LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY
School of Energy Systems
Degree Programme in Energy Technology
Master's thesis

Emilia Heino

Changing Requirements for Air Emission Monitoring and Reporting in Energy Production

Examiners: Professor, D.Sc. (Tech.) Esa Vakkilainen
M.Sc. (Tech.) Kari Luostarinen
Supervisor: M.Sc. (Tech.) Maria Nurmoranta
Tampere 30.3.2021

ABSTRACT

Lappeenranta-Lahti University of Technology (LUT)
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Changing Requirements for Air Emission Monitoring and Reporting in Energy Production
Master's thesis, 2021
80 pages, 29 figures, 5 tables and 1 appendix
Examiners: Professor, D.Sc. (Tech) Esa Vakkilainen, M.Sc. (Tech) Kari Luostarinen
Supervisor: M.Sc. (Tech) Maria Nurmoranta
Keywords: emission monitoring, Industrial Emissions Directive, best available technique, data acquisition and handling system

Emission monitoring and reporting is needed to limit emissions from combustion plants, which remain the greatest source of electricity in the European Union (EU). The purpose of this master's thesis was to clarify the requirements for air emission monitoring and reporting in the EU, focusing on recently published requirements. The new requirements addressed in this study were the Best Available Techniques (BAT) Reference Documents for Large Combustion Plants (LCP) and Waste Incineration (WI) and the standard EN 17255-1, which is the first standard to define minimum requirements for emission data acquisition and handling systems. The study was done in cooperation with Valmet Automation, which offers emission monitoring and reporting systems (EMRS) for power plants. The main objective of the study was to ensure that Valmet's solutions comply with the latest requirements.

The study aimed to clarify the implementation of the requirements and to find out about local interpretations in discussions with Finnish authorities. Also, an operator survey was conducted in order to find out operators' views and needs on the requirements. The discussions with the authorities clarified that the standard EN 17255-1 is not yet included in legislative requirements in Finland. The study stated that the requirements of the standard are not entirely unambiguous, but its implementation is important in harmonizing emission reporting in the EU. The study analyzed calculation results according to the standard's calculation principles in comparison to those acquired by the Valmet DNA WI Emission Reporting solution. The biggest differences in results appeared in periods when the operation mode of the plant changed. The difference was due to the calculations' different validation rules for determining whether a period is reportable or unreportable. Results during normal operation did not differ remarkably.

The updated LCP BAT conclusions were implemented to the Valmet EMRS. Based on the discussions with the authorities, the implementation was done so that the BAT-associated emission limits are monitored simultaneously with the limits of the Industrial Emissions Directive. The solution calculates all the necessary values for compliance monitoring with emission limit values and displays them on daily, monthly and yearly reports. Emissions during Other Than Normal Operating Conditions (OTNOC) are excluded from compliance monitoring. Information of the OTNOC events is recorded to the database and displayed on a summary report.

TIIVISTELMÄ

Lappeenrannan-Lahden teknillinen yliopisto (LUT)
LUT School of Energy System
Energiatekniikan koulutusohjelma

Emilia Heino
Muuttuvat vaatimukset energiantuotannon ilmapäästöjen valvonnassa ja raportoinnissa
Diplomityö, 2021
80 sivua, 29 kuvaa, 5 taulukkoa ja 1 liite
Tarkastajat: Professori, TkT Esa Vakkilainen, DI Kari Luostarinen
Ohjaaja: DI Maria Nurmoranta
Hakusanat: päästöraportointi, teollisuuspäästödirektiivi, paras käyttökelpoinen tekniikka

Päästöjen valvontaa ja raportointia tarvitaan rajoittamaan päästöjä polttolaitoksista, jotka ovat yhä Euroopan Unionin (EU) suurin sähköntuotantomuoto. Tämän diplomityön tarkoituksena oli selvittää ilmapäästöjen valvonnan ja raportoinnin vaatimukset EU:ssa, keskittyen hiljattain julkaistuihin vaatimuksiin. Työssä käsitellyt uudet vaatimukset olivat parhaiden käyttökelpoisten tekniikoiden (BAT) vertailuasiakirjat suurille polttolaitoksille (LCP) ja jätteenpoltolle (WI) sekä standardi EN 17255-1, joka on ensimmäinen standardi päästödatan keruu- ja käsittelyjärjestelmille. Tutkimus tehtiin yhteistyössä Valmet Automationin kanssa, joka tarjoaa päästöjen valvonta- ja raportointisovelluksia voimalaitoksille. Työn päätavoite oli varmistaa, että Valmetin sovellukset noudattavat viimeisimpiä vaatimuksia.

Tutkimuksessa pyrittiin saamaan tietoa vaatimusten toteutuksesta ja paikallisista tulkinnoista yhteistyössä Suomen viranomaisten kanssa. Työn puitteissa tehtiin myös kyselykartoitus, jolla pyrittiin selvittämään toiminnanharjoittajien näkemyksiä ja tarpeita vaatimuksiin liittyen. Viranomaisten kanssa pidetyissä keskusteluissa saatiin selville, että standardi EN 17255-1 ei vielä sisälly lainvoimaisiin vaatimuksiin Suomessa. Tutkimuksessa todettiin, että standardin vaatimukset eivät ole täysin yksiselitteisiä, mutta sen täytäntöönpano on tärkeää päästöraportoinnin yhdenmukaistamiseksi EU:ssa. Tutkimuksessa analysoitiin standardin laskentaperiaatteiden mukaisesti saatuja laskentatuloksia verrattuna Valmet DNA WI Emission Monitoring -sovelluksen tuloksiin. Analyysissä selvisi, että tulosten suurimmat erot ilmenevät ajotilanteiden muuttuessa, sillä laskennoilla on erilaiset säännöt ajanjakson hyväksymiseksi raportointiin. Normaaliajossa laskentojen tulokset eivät eronneet merkittävästi.

Päivitettyjen LCP BAT-päätelmien vaatimukset toteutettiin Valmetin päästö-raportointisovelluksiin. Viranomaisten kanssa käytyjen keskustelujen pohjalta toteutus tehtiin niin, että BAT raja-arvoja seurataan teollisuuspäästödirektiivin raja-arvojen kanssa samanaikaisesti. Sovellus laskee kaikki tarvittavat arvot raja-arvotarkkailua varten ja tallentaa ne vuorokausi-, kuukausi- ja vuosiraporteille. Muiden kuin normaaliajotilanteiden (OTNOC) aikana tuotetut päästöt eivät sisälly raja-arvotarkkailuun. Tiedot OTNOC-tilanteista talletetaan tietokantaan ja esitetään yhteenvetoraportilla.

FOREWORD

This study has been an interesting journey to the world of emission monitoring and reporting. I would like to express my gratitude to the Finnish authorities who took part in the discussions during this thesis and the power plant operators who participated in the operator survey. Thanks to Valmet Automation for giving me the opportunity to do this thesis even in the middle of the pandemic. I want to thank my supervisor Maria Nurmoranta, who has guided and supported me throughout this study. Thanks to my co-workers Leena Riihimäki, Marika Salmela and Visa Pesonen for all the valuable advices and help during the work. I also want to thank Elina Kleemola for the help during this thesis, especially with the operator survey. Thanks to the colleagues in Tampere office for the nice and entertaining coffee and lunch breaks.

I want to thank Esa Vakkilainen for giving interesting lectures during my studies and for examining this master's thesis. Thanks also to my fellow student Pinja who gave comments and helped to proof-read this thesis. Lastly, I want to thank my family and Tommi for their endless support. Thanks for encouraging me whenever I doubt myself.

Tampere 30.3.2021
Emilia Heino

TABLE OF CONTENTS

Abstract

Tiivistelmä

Foreword

Table of Contents

List of Symbols and Abbreviations

1 Introduction... 9

2 Air Emissions and Emission Control in Energy Production 12
2.1 Pollutants.. 14
2.2 Abatement Techniques.. 16
2.3 Advanced Process Control 18

3 Requirements for Emission Monitoring in Energy Production 20
3.1 Industrial Emissions Directive 21
3.2 Best Available Techniques Reference Documents 23
3.2.1 BAT Reference Document for Large Combustion Plants 24
3.2.2 BAT Reference Document for Waste Incineration.. 26
3.3 Finnish Legislation.. 26
3.3.1 Government Decree on Limiting Emissions from Large Combustion Plants 27
3.3.2 Government Decree on Waste Incineration... 28
3.4 Other Directives 29
3.5 Future 30

4 Continuous Emission Monitoring Systems.. 33
4.1 Emission Analyzers... 34
4.2 Quality Assurance of Automated Measuring Systems... 36
4.3 Uncertainty of the Measurements 38
4.4 Requirements for Data Acquisition and Handling Systems..................................... 40
4.4.1 Calculation Principles.. 42
4.4.2 Validity and Status of Data.. 43
4.4.3 Reporting Requirements 46
4.5 Valmet DNA Emission Monitoring and Reporting System.................................... 46

5 Discussion on Recent Requirements for Emission Monitoring and Reporting 51
5.1 Updated LCP and WI BAT Reference Documents... 51
5.2 EN 17255-1: Specification of Requirements for the Handling and Reporting of Data54
5.3 Operator Survey 57

6 Valmet EMRS Compliance with Recent Requirements... 61
6.1 Comparison of Current Valmet DNA WI Emission Monitoring Results Against EN 17255-1 Calculation and Validation Rules.. 61
6.2 Implementation of LCP BAT Conclusions 65

7 Conclusions **70**

References **72**

Appendices

Appendix I: Comparison of results from Valmet DNA WI Emission Monitoring application and the calculation according to calculation principles and validation rules of the standard EN 17255-1.

LIST OF SYMBOLS AND ABBREVIATIONS

Latin alphabet

c	concentration	mg/m^3
h	water vapour content	%
k	confidence factor	%
o	oxygen content	%
p	pressure	bar
t	time	s
T	temperature	K
Q	volumetric flow	m^3/s
X	mass	kg

Subscripts

F	flow
fg	flue gas
m	measured
p	pollutant
pme	pollutant mass emission
ref	standard condition

Abbreviations

AMS	Automated Measuring System
AST	Annual Surveillance Test
BAT	Best Available Technique
BAT-AEL	BAT-Associated Emission Level
BREF	Best Available Techniques Reference Document
CEMS	Continuous Emission Monitoring System
DAHS	Data Acquisition and Handling System
DCS	Distributed Control System
ELV	Emission Limit Value
EMRS	Emission Monitoring and Reporting System

ESP	Electrostatic Precipitator
ETS	Emission Trading System
EU	European Union
FGD	Flue Gas Desulfurization
FLD	First Level Data
FTIR	Fourier Transform Infrared Spectroscopy
GHG	Greenhouse Gas
IED	Industrial Emissions Directive
IR	Infrared Spectroscopy
LCP	Large Combustion Plant
LTA	Long-Term Average
MCP	Medium Combustion Plant
MCPD	Medium Combustion Plant Directive
NOC	Normal Operating Conditions
NTP	Normal Temperature and Pressure
OTNOC	Other Than Normal Operating Conditions
QA	Quality Assurance
QAL1	First Quality Assurance Level
QAL2	Second Quality Assurance Level
QAL3	Third Quality Assurance Level
SCR	Selective Catalytic Reduction
SNCR	Selective Non-Catalytic Reduction
SSTA	Standardized Short-Term Average
STA	Short-Term Average
TNP	Transitional National Plan
VSTA	Validated Short-Term Average
WI	Waste Incineration

1 INTRODUCTION

Even though the energy industry is moving towards more environmentally friendly technologies, it is still one of the greatest polluters in the world. The industry is mainly driven by fossil fuels, including coal, natural gas and oil. As of 2018, coal was the greatest source of electricity generation in the world with the share of 38 %. (IEA 2020) In the European Union (EU), the share of solid fossil fuels was 20,2 % of the total gross electricity production. Renewables and biofuels were utilized the most with the share of 32,9 %. Although an increasing proportion of municipal waste is being incinerated for energy generation in the EU, its share was still only 0,7 %. (Eurostat 2020a) The EU's gross electricity production by source in 2018 is shown in Figure 1.

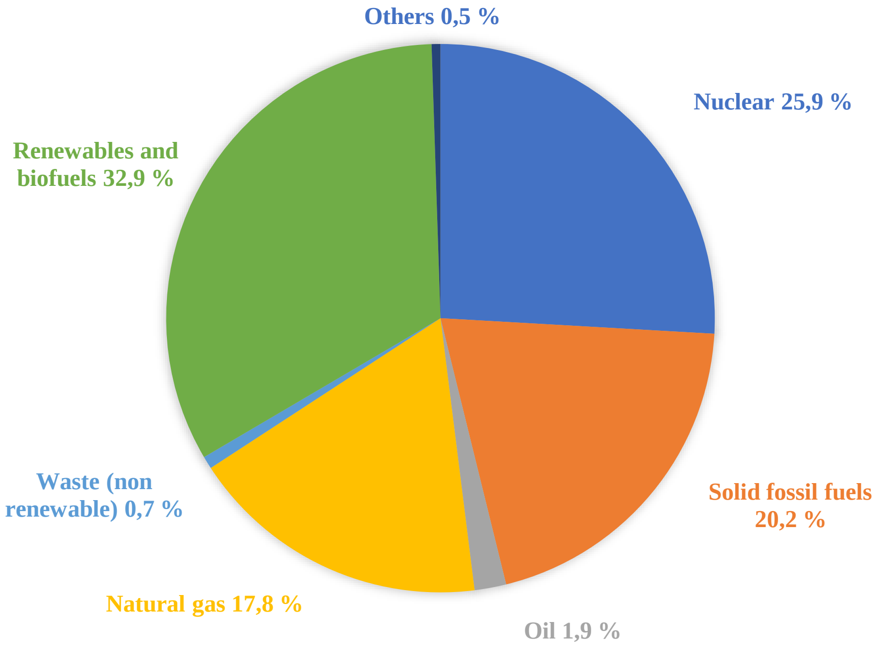


Figure 1. The sources of gross electricity production in the EU in 2018 (Eurostat 2020a).

With the share of 42,8 %, combustion plants are clearly the greatest type of electricity production in the EU (Eurostat 2020b, 3). When fuels, such as coal, natural gas, biofuels and waste are burned in combustion plants, various harmful emissions for the nature and human health are emitted to the air. Typical emissions from combustion plants are carbon dioxide (CO_2), nitrogen oxides (NO_x), sulphur dioxide (SO_2), carbon monoxide (CO) and particulate matter. However, the variety and amount of emissions depend on the fuel utilized. Also, the boiler type, combustion conditions and abatement techniques used affect the emissions.

Emission monitoring is needed to limit the emissions produced by combustion plants. Emission monitoring means that production units measure their emissions in accordance with relevant legislation, and report them to a competent authority. Proper emission monitoring requires the plants to mitigate their emissions and to invest in environmentally friendly technologies. This study covers the monitoring of emissions to air from Large Combustion Plants (LCPs), Waste Incineration (WI) plants and waste co-incineration plants in the EU. Large combustion plants are those whose capacity is equal or greater than 50 MW and co-incineration plants are those in which waste is co-incinerated with other fuels. The monitoring of emissions to water and soil are excluded from the scope of the study

In the EU, emissions from energy production are regulated by several directives, of which the most important regarding this study is the Industrial Emission Directive (IED). The directive covers non-greenhouse gas emissions from industrial installations. It entered into force in 2013 and required environmental permits of the plants concerned to be reviewed. The directive sets minimum requirements for the plants, but state, that permit conditions must be set on the basis of Best Available Techniques (BAT), which are defined in industry-specified BAT Reference Documents (BREFs). The recently updated LCP and WI BREFs tighten the monitoring requirements of the IED, and thus, a new review of environmental permits is required.

To fulfill the monitoring and reporting requirements of the IED, power plants need a continuous emission monitoring system (CEMS). A CEMS measures and stores emission data, calculates required outputs, and produces reports to display the data. A CEMS consists of emission analyzers and a data acquisition and handling system, which can also be reffered to as an Emission Monitoring and Reporting System (EMRS). The quality and reliability of emission monitoring and reporting is ensured by standards of the European Committee for Standardization (CEN). The standards have previously set requirements for the quality assurance of emission analyzers but a new standard series EN 17255 sets requirements also for the emission data acquisition and handling systems.

The purpose of this study is to clarify the requirements for air emissions monitoring and reporting in energy production in the EU, focusing on recently published requirements. In this study, recently published requirements refer to the LCP BREF published in 2017, the WI BREF published in 2019 and the EN standard 17255-1 published in 2019. The study is done in cooperation with Valmet Automation, which, as a part of its product portfolio, offers performance solutions for power plants. The solutions include emission monitoring and reporting applications for large combustion, waste incineration and waste co-incineration plants. The aim of this study is to ensure that Valmet's emission monitoring and reporting solutions comply with the latest requirements. As a part of the study, discussions are held with Finnish authorities to clarify the implementation of the requirements and to find out about local interpretations. Also, a survey for power plant operators will be conducted in order to find out the views and needs of the operators regarding the new requirements.

The second chapter of this study introduces the typical air emissions and emission control techniques in energy production. It describes the reasons for limiting emissions and the possible ways to control them. The third chapter gives an overview of the legislative requirements for emission monitoring in the EU. It introduces the IED, BREFs and the Finnish legislation on emission monitoring. It also gives a brief look in the future of the requirements for emission monitoring. Further, the fourth chapter describes the components of a CEMS and the requirements on them, including the EN 17255 standard series. The fifth chapter includes discussion on the recent requirements for emission monitoring and reporting. It describes the outcomes of the discussions with the Finnish authorities and the operator survey. Finally, the sixth chapter addresses the compliance of the Valmet EMRS with the recent requirements.

2 AIR EMISSIONS AND EMISSION CONTROL IN ENERGY PRODUCTION

Harmful emissions to the environment and human health are released into the air when fossil fuels, combustible renewable fuels and waste fuels are burned in energy production. A combustion process produces a wide variety of emissions, including organic and inorganic compounds. The amount and variety of emissions produced depend on the fuel, boiler type, combustion conditions and the abatement techniques utilized. (Russell 2013, 45)

Typical emissions to air from a combustion process are sulphur dioxide (SO_2), nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter (PM, dust) and greenhouse gases (GHG). In addition, smaller quantities of hydrogen chloride (HCl), heavy metals, hydrogen fluoride (HF), unburnt hydrocarbons, volatile organic compounds (VOC) and dioxins can be emitted. (European Commission 2017, 18) As an example, reported emissions to air in 2017 from one of the biggest power plants in the EU are shown in Figure 2. The power plant is biomass- and coal-fired and its total power is around 4000 MW. The CO_2 emissions of the plant were 16,6 million tons in 2017. (EEB)

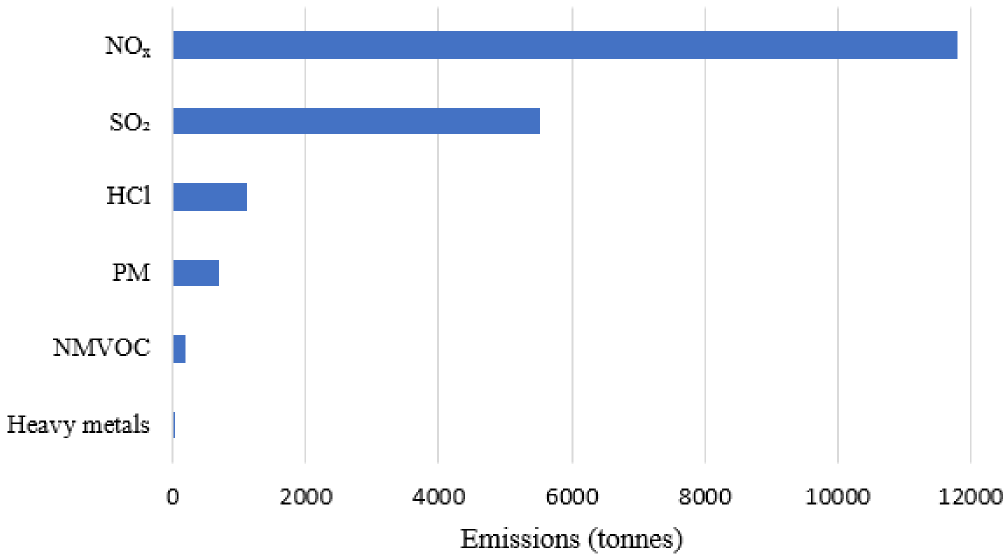


Figure 2. Emissions from a power plant with the power of 4000 MW in 2017 (EEB).

The development of non-GHG air emissions from energy production is reflected in the EEA's Air quality in Europe -report (2020a). The report provides trends of emissions from main sectors contributing to air pollution. The figures include pollutants for which the sector contributed more than 5 % of the total EU emissions in 2018. In energy supply such emissions are NO_x, SO_2 and heavy metals, including cadmium (Cd), mercury (Hg), arsenic (As), nickel (Ni) and lead (Pb). Figure 3 and Figure 4 show the development of these emissions from energy supply from 2000 to 2018 in the EU. Energy supply includes fuel production, fuel processing and energy production.

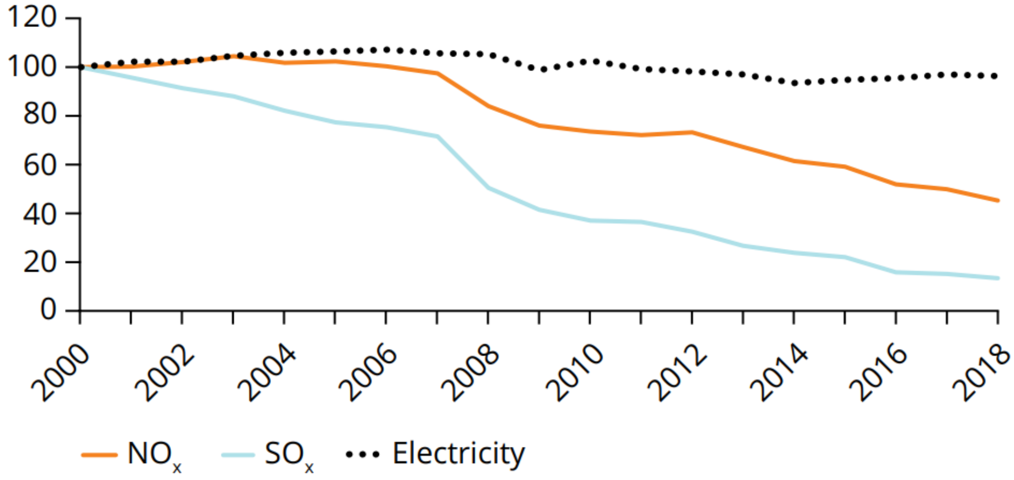


Figure 3. Development of NO_x and SO_2 emissions in energy supply (EEA 2020a, 33).

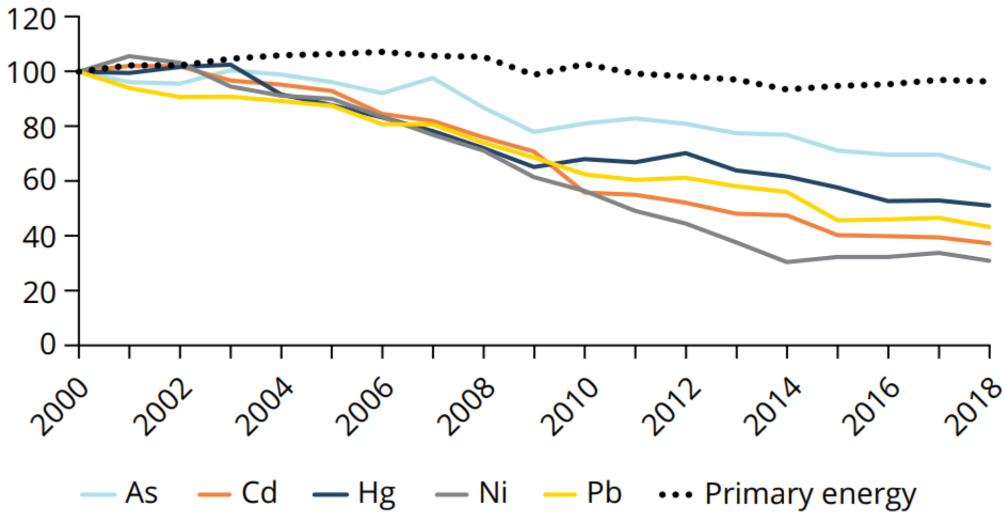


Figure 4. Development of heavy metal emissions in energy supply (EEA 2020a, 34).

As it can be seen from the Figure 3, the emissions of SO_2 and NO_x have decreased considerably since 2000 even though electricity consumption has remained at the same level. The Figure 4 shows that the trend for heavy metals has been similar. Driving forces for the reductions have been policy actions and the transition to cleaner energy production. The use of renewable energy has doubled from 2005 to 2018 in the EU and therefore also greenhouse gas emissions associated to fossil fuels have decreased remarkably. However, the increase in biomass burning has made PM and VOC emissions to grow compared to the level in 2005. This kind of interplay between renewable and non-renewable energy sources need to be considered by policymakers in order to maximize the climate and health benefits of the energy transition. (EEA 2020b) All in all, the trends show that the direction is right, and emissions have generally been decreased.

To understand the need for emission monitoring in energy production, it is important to know the adverse impacts of the emissions produced. Hence, the most important air pollutants from combustion plants and their environmental and health impacts are introduced in the chapter 2.1. Various techniques can be used to mitigate emissions during or after combustion. The most common abatement techniques utilized in power plants are introduced in the chapter 2.2. The chapter focuses on other control techniques than advanced process control, which is described in the chapter 2.3.

2.1 Pollutants

Combustion plants are the main source of SO_2 and NO_x emissions to air from industrial installations in the EU. Nitrogen oxides include nitrogen monoxide (NO) and nitrogen dioxide (NO_2). The amount SO_2 and NO_x emissions emitted from a combustion process depends on the fuel content. For example, coal has a high sulphur content whereas natural gas is considered to be sulphur-free. Nitrogen contents of coal and peat are greater than of other fuels. The amount of NO_x emissions depends also on the combustion temperature and the amount of oxygen in the reaction medium. (European Commission 2017, 20-22; VTT 2016, 206, 186) SO_2 and NO_x cause acidification and eutrophication of waters and soils. In addition, they cause health problems to humans such as airway inflammation and reduced lung function. (EEA 2020c, 17)

Energy production is one of the greatest contributors to climate change. In 2017, energy industry was responsible for 29 % of total greenhouse gas emissions in the EU. Greenhouse gases cover a group of gases that contribute to global warming and climate change, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and sulphur hexafluoride (SF_6). (Eurostat 2020c) CO_2 accounts for the major proportion of greenhouse gases from power plants and results from burning of fossil fuels. Burning biomass produces CO_2 emissions as well, but the carbon in biomass is of biogenic origin. Hence, biomass is considered to be carbon neutral, unlike fossil fuels, whose CO_2 has been trapped in geologic formations for millennia. (Gillenwater 2005, 4, 10)

Particulate matter is one of the most harmful pollutants to humans. It can cause cardiovascular and lung diseases as well as cancers. (EEA 2020c, 17) Combustion plants are the main source of PM emissions to air from industrial installations in the EU. PM from the combustion of coal, peat and biomass results almost entirely from the mineral fraction of the fuel. The particles released to air depend on the proportion of ash in flue gas, which depends on the combustion process. The amount of fly ash in moving grate boilers is relatively small whereas pulverized coal boilers produce it a considerable amount. (European Commission 2017, 23-24) Heavy metals pollute the air and can also build up on soils and sediments and bio-accumulate in food chains (EEA 2020c, 17). Heavy metals result from combustion process due to their presence as natural substances in fuels. Coal contains normally significantly higher level of heavy metals than, for example, oil and natural gas. (European Commission 2017, 23)

Hydrogen chloride emissions result from the presence of chloride in fuels, such as fossil fuels and biomass. HCl is formed when the chloride released during combustion combines with hydrogen. With the moisture in the air, HCl transforms to a hydrochloric acid aerosol that causes acidification problems. Hydrogen fluoride (HF) is formed similarly, as fluoride from the combustion combines with hydrogen. HF transforms to hydrofluoric acid when reacting with the moisture in the air. CO is always present as intermediate product in the combustion process. (European Commission 2017, 26, 30-31) High carbon monoxide concentration in the air causes negative effects to human health, such as headache and increased risk of chest pain for persons with heart disease (National Research Council 2002, 19). The formation of CO can be prevented with right combustion conditions, including combustion temperature and oxygen content of the reaction medium. (European Commission 2017, 26)

Ammonia (NH_3) causes eutrophication and acidification of waters and soils (EEA 2020c, 17). Ammonia emissions do not result from combustion process, but from NO_x prevention techniques, in which ammonia is used as a reagent. Ammonia emissions to air from the abatement techniques are called ammonia slip. (European Commission 2017, 32) Organic pollutants in the atmosphere cause various harmful effects on human health and ecosystems (EEA 2020c, 17). The most important persistent organic pollutants from combustion processes are polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-dioxins (PCDD) and polychlorinated dibenzo-furans (PCDF). Organic pollutants can result from their presence in the fuel or they can form during combustion. PAHs are present for instance in fossil and waste fuels. Along with coal, PCDD/F can appear for example in wood that has been treated with chlorinated organic compounds. (European Commission 2017, 33-34)

Volatile organic compounds include several organic compounds that have different chemical compositions but behave similarly in the atmosphere. The group of compounds can be referred as non-methane volatile organic compounds (NMVOCs), which means that methane is excluded from the group. NMVOCs cause ground level ozone formation. In addition, some of the compounds, such as benzene, are hazardous to human health. (EEA 2010) Total volatile organic carbon (TVOC) emissions include various gaseous organic substances which are difficult or impossible to detect individually. These emissions result from incomplete reactions in incineration. TVOCs are formed particularly in the combustion of waste. Low TVOC emission levels indicate good quality of combustion. (European Commission 2019a, 147)

2.2 Abatement Techniques

Emission abatement techniques can be divided into two categories: primary and secondary techniques. Primary techniques include control of combustion conditions and injection of absorbent materials into the furnace. Secondary techniques are applied to the flue gas after combustion in order to remove certain pollutants. (EEA 2019, 4, 12) The chapter 2.3 focuses on combustion control whereas this chapter addresses the other techniques.

Sulphur dioxide emissions can be reduced by injecting absorbent material, typically lime, into the furnace. This technique is common in fluidized bed combustion, where reduction efficiency is high because of the recirculation of the bed. However, post combustion flue gas desulphurization (FGD) techniques are more common for SO_2 removal. Most common of these techniques are lime/limestone wet scrubbing, spray dryer absorption and dry sorbent injection. The techniques are based on the reaction of SO_2 with an alkaline agent to form salt. Also, SO_3, fluorides and chlorides are reduced by secondary reactions that happen in the desulphurization process. The process can also reduce particulate and metal emissions, such as mercury. For wet scrubbing and spray dryer absorption the reduction efficiency of SO_2 is over 90 %. (EEA 2019, 11)

Primary techniques to minimize the formation of nitrogen oxides are low-NO_x burners, staged air supply, flue gas recirculation, overfire air, reburn and water/steam injection. Varying degrees of NO_x reduction can be achieved with these techniques. The type of combustion process affects NO_x emissions as well – the emissions in fluidized bed boiler are lower than in conventional boilers. Secondary techniques for the removal of NO_x include selective non-catalytic reduction (SNCR) and selective catalytic reduction (SCR). In the SNCR process, ammonia or urea is injected to flue gas near the furnace. SCR technique is based on the injection of ammonia and urea with the presence of a catalyst. NO_x reduction efficiency up to 50 % can be achieved with SNCR, whereas reduction efficiency of 70 - 90 % can be achieved with SCR. (European Commission 2017, 21; EEA 2019, 12)

Electrostatic precipitators (ESPs) and bag filters are the main technologies used for the removal of particulate matter from flue gases (EEA 2019, 12). The abatement techniques of PM are very efficient, resulting in more than 99.8 % reduction rate. However, small particles cannot be reduced so efficiently and thus the particles emitted to air are mostly in the diameter range of 0.1 µm to 10 µm. Health impacts are greatest with particles with a diameter less than 2.5 µm. (European Commission 2017, 23) FGD and wet scrubbers can also be effective in dust abatement. Heavy metals, which appear in a particulate phase, are also reduced with dust abatement techniques. (EEA 2019, 12) An example configuration of emission abatement techniques in a power plant is presented in Figure 5.

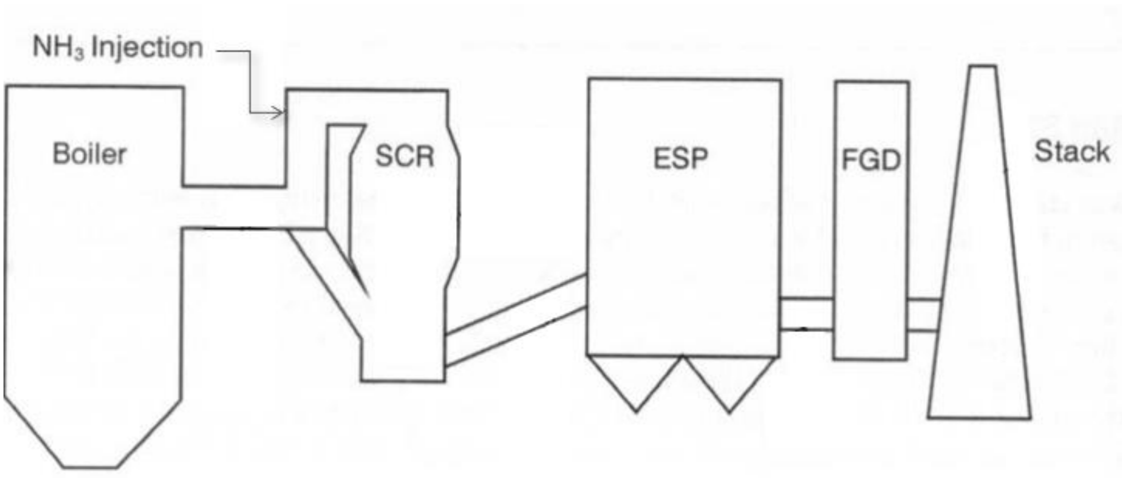


Figure 5. An example configuration of emission control techniques in a power plant (Modified from source: Feeley et al 2003, 5).

2.3 Advanced Process Control

Varying combustion conditions, fuel quality and changing loads deteriorate combustion efficiency and increase flue gas emissions. Computer-based advanced control systems can be utilized to improve the combustion process and to reduce emissions. Advanced process control generally brings extensions and improvements to classical control methods and they can be applied for both new and existing installations. In advanced process control, a sensor provides data to a decision maker, which sends the signal to an actuator for reaction. By advanced control, heat loss due to unburnt gases, solid wastes and residues is reduced. Due to the improvement, boiler efficiency is optimized and unburnt substances as well as the concentration of NO_x in the flue gas are reduced. (Szentennai & Lackner 2014; European Commission 2017, 266)

Unburnt gases can be divided into two main groups: CO and hydrocarbons. They result of incomplete combustion, which can be caused by excessively low combustion temperature, too short residence time in the combustion zone or inefficient mixing of the fuel and combustion air. NO_x emissions are affected by excess air level and the combustion air temperature. If the temperature of the combustion process is below 1000 °C, significantly lower NO_x emissions can be achieved. The control of excess air level for NO_x reduction may increase emissions of the unburnt gases and in that case, ensuring efficient mixing of air and fuel is important. Correct distribution of fuel and air in the combustion chamber affect largely the boiler efficiency and NO_x generation. (European Commission 2017, 21, 266-267)

To control these issues in the combustion process, several factors can be monitored. These factors include, for example, combustion temperature, temperature profile, inlet air excess, flue-gas oxygen content, NO_x/CO balance and air to fuel ratio at each burner or row of burners. (European Commission 2017, 266) Based on these factors and algorithms installed to the advanced control system, the system defines setpoints that are used to control the process. Figure 6 demonstrates the principles of an advanced control system.

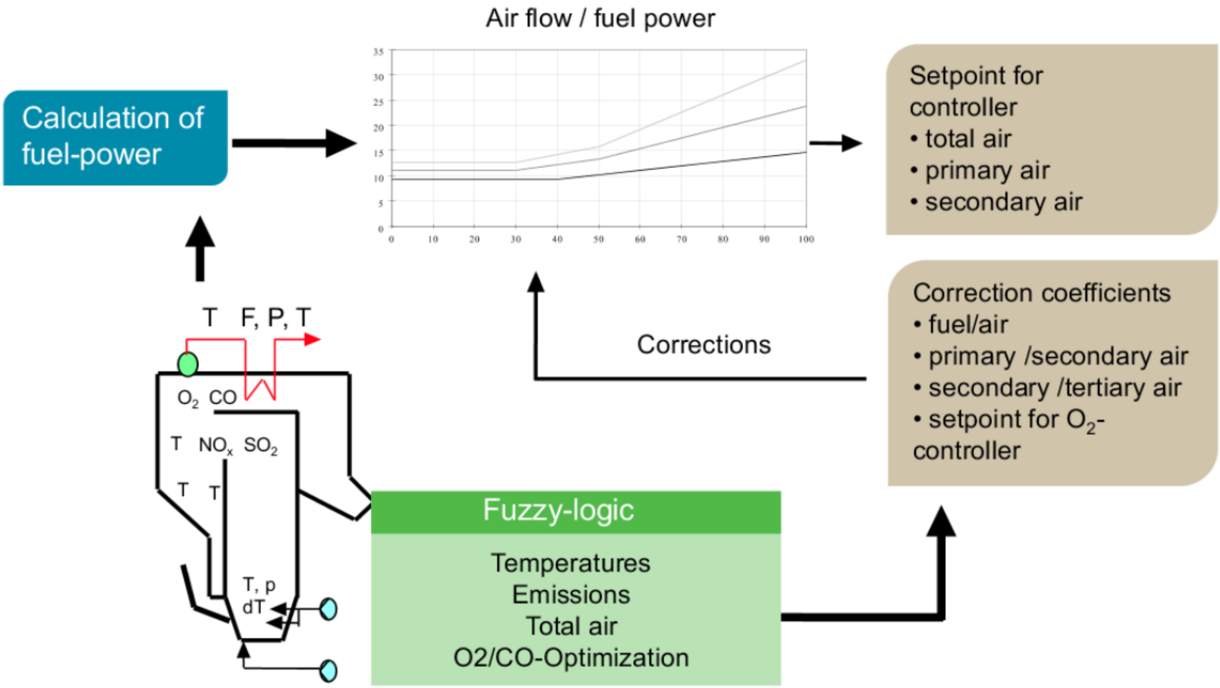


Figure 6. Principles of an advanced control system (Valmet 2017).

3 REQUIREMENTS FOR EMISSION MONITORING IN ENERGY PRODUCTION

The purpose of emission monitoring is to protect the environment and the human health from harmful pollutants as well as to combat the climate change. In the EU, emissions from energy production are regulated by directives and Member States' national legislation. The directives regulate pollution from individual sources but also set national and EU-wide totals for key atmospheric emissions. The directives set basic standards for Member States but often allow them to determine more stringent requirements at the national level. The directives on emission monitoring are set under the categories of air quality and climate change in the EU environmental policy. (WECOOP)

The Industrial Emissions Directive (IED) regulates non-GHG emissions from individual industrial sources. The directive requires that emission mitigations are achieved with best available techniques (BAT), which are presented in industry-specified BAT Reference Documents. Medium Combustion Plant Directive (MCPD) regulates emissions from non-IED plants, i.e. those, whose power is smaller than 50 MW. Both the IED and the MCPD limit emissions at the micro-level, whereas National Emission Reduction Commitments Directive regulates emission at the macro-level by setting nationwide emission reduction commitments for certain non-GHG pollutants. The EU Emission Trading System (ETS) sets an EU-wide target for GHG emissions. (WECOOP) The regulations are summarized in Figure 7.

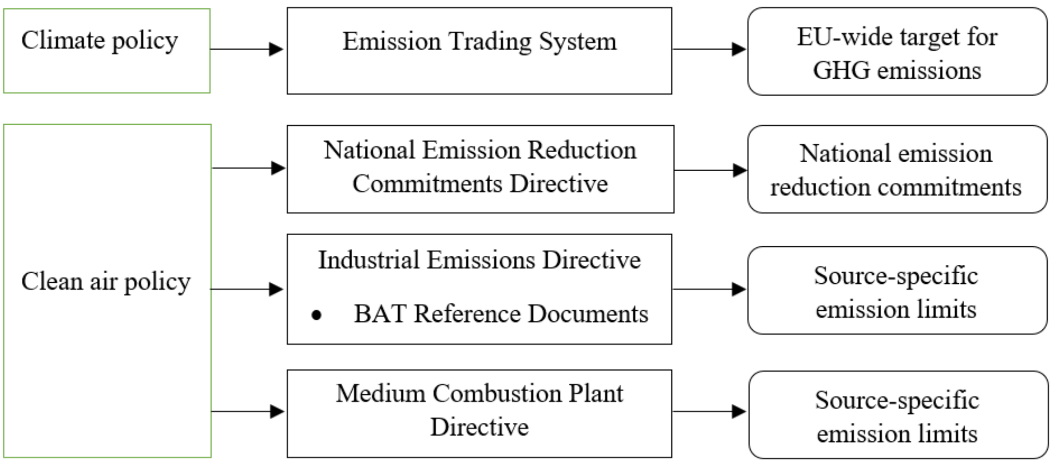


Figure 7. EU regulations on emission monitoring.

This study focuses on emission monitoring and reporting under the IED, which is introduced in the chapter 3.1. BAT Reference Documents are presented in the chapter 3.2 and the Finnish legislation related to emission monitoring and the IED is described in the chapter 3.3. The other EU directives on emission monitoring are introduced in the chapter 3.4. Finally, the future of requirements for emission monitoring is addressed in the chapter 3.5.

3.1 Industrial Emissions Directive

Industrial Emissions Directive (2010/75) is the European Union's main instrument for preventing and controlling emissions from industrial production processes. It combines several previously existed directives, including Large Combustion Plants and Waste Incineration Directives, and provides a framework for regulating emission to air, water and soil of about 50 000 industrial installations in the EU. It was published in 2010 and had to be transposed by Member States by 7 January 2013. (European Commission 2020a)

The directive relies on several principles, of which the most important are:

- **Integrated approach**. Emissions to air, soil and water are monitored together, protecting the environment as a whole.
- **Best Available Techniques**. The plan for the reduction of emissions is to use best available techniques. BATs are presented in industry-specified BAT Reference Documents.
- **Flexibility**. In certain cases, competent authorities can set less strict emission limit values. It provides certain flexibility instruments, such as Transitional National Plan.
- **Environmental inspections**. Visits to sites are required at least every 1 to 3 years.
- **Public participation**. Public can participate in decision-making process and is informed of its consequences. (European Commission 2020a)

The IED sets minimum requirements, including Emissions Limit Values (ELVs), for LCPs and WI plants. ELVs are set for instance for SO_2, NO_x, dust and CO. The directive also determines the conditions under which the emission limit values are met and how the measurement uncertainty is taken into account. According to the directive, emission monitoring shall be carried out in accordance with CEN standards and if those are not available, then ISO, national or other international standards may be used to ensure the scientific quality of the emission data. (Directive 2010/75/EU)

According to the IED, permit conditions should be set on the basis of best available techniques. In order to determine the BATs, an exchange of information between experts is organized by the Commission. The resulting BREFs from the information exchange can set stricter industry-specified requirements than the minimum requirements defined in the IED. (European Commission 2020b, 9-10) However, until environmental permits are reviewed with the resulting BREFs, the emission limit values shall be according to the limits provided in the IED (European Commission 2020c). Each Member State must implement the objectives of the IED to their national legal frameworks. The requirements of the directive are described more detailed in chapter 3.3, which addresses the Finnish environmental legislation and the implementation of the directive. The implementation process of the IED is described in Figure 8.

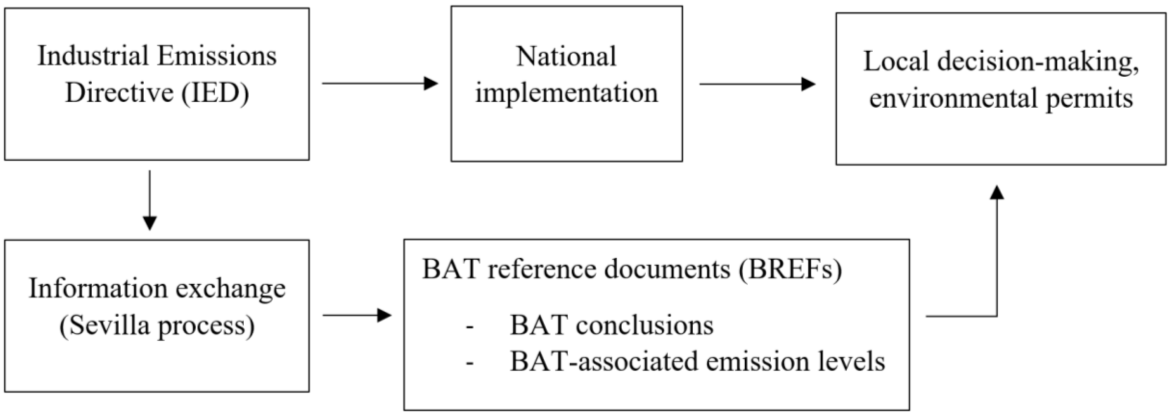


Figure 8. The implementation process of the IED (Modified from source: SYKE 2020).

For LCPs that meet specific conditions, the IED provides flexibility mechanisms to set temporary exemptions from the ELVs set in the directive. These flexibility mechanisms are Transitional National Plan (TNP), limited lifetime derogation, small isolated systems and district heating plants. The TNP determines maximum total annual emissions allowed for all the installations covered by the plan. Plants were eligible for the plan if they were granted their first permit before 27 November 2002 or if the permit was submitted before that date and the operation started no later than 27 November 2003. The TNP was in force from 1 January 2016 to 30 June 2020. (European Commission 2020c)

Limited lifetime derogation could be applied for the plants that would not operate more than 17 500 hours between 1 January 2016 and 31 December 2023. If a plant was part of a small isolated system on 6 January 2011, it was eligible for an extended period to comply with the IED, having a deadline on 31 December 2019. A district heating plant supplying steam or hot water to a public district heating network was also eligible for an extended period to comply with the requirements, ending on 31 December 2022. (European Commission 2020c)

3.2 Best Available Techniques Reference Documents

Best available techniques reference documents are outcome from information exchange between experts from Member States, industry and environmental organizations in so-called Sevilla process (European Commission 2020a). The BREFs determine industry-specific Best Available Techniques and introduce emerging technologies that may be applicable for the industry in the near future of the publication time. The BREFs are continuously reviewed in order to reflect the development of technology and new emerging techniques. (European Commission 2017) Figure 9 explains the concept of best available techniques.

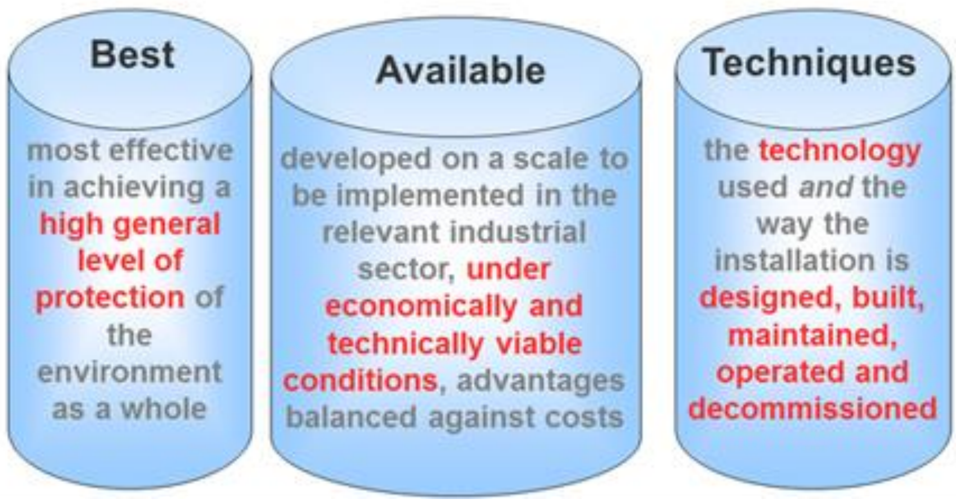


Figure 9. Definition of Best Available Techniques (European Commission).

BAT conclusions are a form part of every BREF. The conclusions sum up the best available techniques to improve environmental performance, set monitoring requirements and define BAT-associated energy efficiency levels and BAT-associated emission levels (BAT-AELs). The BAT-AELs include emissions limit values for emissions to air and water. (European Commission 2017) The BAT-AELs in the new BREFs are binding, except where the implementation of BAT would cause disproportionately higher costs compared to the environmental benefits. The other BAT conclusions, including the energy efficiency levels, are not binding. (European Commission 2019b)

Regarding this study, the most important BREFs are the BAT Reference Document for Large Combustion Plants, introduced in the chapter 3.2.1 and the BAT Reference Document for Waste Incineration, introduced in the chapter 3.2.2.

3.2.1 **BAT Reference Document for Large Combustion Plants**

Best Available Techniques Reference Document for Large Combustion Plants (LCP BREF) covers the combustion of fuel in plants with total rated thermal input of 50 MW or more, including waste co-incineration in most cases. It also covers gasification of coal or other fuels in plants with total rated thermal input of 20 MW or more, only when gasification is directly associated to a combustion plant. The document defines the most important issues in the LCP industry as emissions to air, emissions to water resulting from wet abatement techniques for the removal of SO_2, resource efficiency and energy efficiency. (European Commission 2017)

The requirements set in the BAT conclusions are defined separately for different processes (combustion and gasification) and fuel types (e.g. solid and liquid). Emission limit values are set for NH_3, NO_x, SO_2, HCl, HF, organic compounds, dust and metals including mercury. The BAT-AELs are defined as daily and yearly averages or averages over the sampling period. Most of the BAT-AELs are different for existing and new plants. Plants that have been granted an environmental permit after the publication of the BREF are considered as new plants. (European Commission 2017) As an example, the emission levels for SO_2

emissions to air from the combustion of solid biomass and/or peat in the updated LCP BREF are shown in Figure 10.

Combustion plant total rated thermal input (MW_{th})	BAT-AELs for SO_2 (mg/Nm^3)			
	Yearly average		Daily average or average over the sampling period	
	New plant	Existing plant (1)	New plant	Existing plant (2)
< 100	15–70	15–100	30–175	30–215
100–300	< 10–50	< 10–70 (3)	< 20–85	< 20–175 (4)
≥ 300	< 10–35	< 10–50 (3)	< 20–70	< 20–85 (5)

(1) These BAT-AELs do not apply to plants operated < 1 500 h/yr.
(2) For plants operated < 500 h/yr, these levels are indicative.
(3) For existing plants burning fuels where the average sulphur content is 0.1 wt-% (dry) or higher, the higher end of the BAT-AEL range is 100 mg/Nm^3.
(4) For existing plants burning fuels where the average sulphur content is 0.1 wt-% (dry) or higher, the higher end of the BAT-AEL range is 215 mg/Nm^3.
(5) For existing plants burning fuels where the average sulphur content is 0.1 wt-% (dry) or higher, the higher end of the BAT-AEL range is 165 mg/Nm^3, or 215 mg/Nm^3 if those plants have been put into operation no later than 7 January 2014 and/or are FBC boilers combusting peat.

Figure 10. BAT-associated emission levels for SO_2 from the combustion of solid biomass and/or peat (European Commission 2017, 766).

The update of the LCP BREF, published in 2017, requires environmental permits of the plants concerned to be reviewed within four years of the publication time. The update tightened the emission limit values for pollutants including SO_2 and NO_x and set new emission limit values for pollutants that were previously not regulated. New limits were set to Hg, HCl and HF from the combustion of solid fuels. Also, an emission limit was set to NH_3 when SCR and/or SNCR is used. According to the updated BREF, N_2O must be monitored once every year in fluidized bed boilers although it does not have a limit. (European Commission 2017)

The updated BREF introduced also changes in the monitoring requirements. The emission limit values are effective only during normal operation but Other Than Normal Operating Conditions (OTNOC) must be monitored. A management plan must be set up and implemented in order to reduce emissions during OTNOC. Typical OTNOC are start-ups and shutdowns. Other OTNOC can be, for example, malfunction of abatement equipment, fuel availability problems and testing periods. (European Commission 2017)

3.2.2 BAT Reference Document for Waste Incineration

Best Available Techniques Reference Document for Waste Incineration (WI BREF) addresses the disposal or recovery of waste in waste incineration and waste co-incineration plants in certain cases. The document covers also the treatment of slags and bottom ashes from the incineration of waste. According to the WI BREF, important issues in waste incineration are emissions to air and water, as well as the efficiency of the recovery of energy and of materials from the waste. The emissions to air that must be continuously monitored are dust, HCl, HF, SO_2, NO_x, TVOC, CO, Hg, NH_3. Heavy metals (excl. Hg), PCDD/F compounds and dioxin-like PCBs must be monitored at certain frequency. The BAT-AELs are defined as daily averages or averages over the sampling period. The emission limits are specified separately for new and existing plants. (European Commission 2019a)

The updated WI BREF was published in 2019 and plants concerned must comply with the new requirements by 2023. In the update, the emission limit values of dust, NO_x, SO_2, HCl, metals and PCDD/F were tightened. New continuous emission monitoring requirement was set to Hg and NH_3. Other new monitoring requirements were long-term sampling of polychlorinated dioxins and furans. (European Commission 2019c) As the LCP BREF, also the WI BREF requires now monitoring of N_2O in fluidized bed boilers. Similarly, emission limit values are effective only in normal operation but OTNOC must be monitored. (European Commission 2019a)

3.3 Finnish Legislation

The Environmental Protection Act and Decrees enacted on the basis of the Act are Finland's main tools for protecting the environment from industrial pollution and for the implementation of the IED. The first version of the Environmental Protection Act was published in 2000 and the latest update came into force on 1 September 2014. Regarding this study, the most important Decrees enacted on the basis of the Act are the Government Decree on Limiting Emissions from Large Combustion Plants and the Government Decree on Waste Incineration. The Decrees set the requirements prescribed in the IED to Finnish legislation.

In practice, the Act and the Decrees are taken into force in environmental permits. According to the Act, the actors, who pose a risk of environmental pollution, need an environmental permit. The permit is issued by an environmental authority, usually the regional state administrative agency. The compliance with the permit during the installation's life cycle is monitored by the Centre for Economic Development, Transport and the Environment (ELY Centre). (Toikka 2020) The emission limit values and monitoring requirements in the permits are based on the Decrees and the BAT Reference Documents.

3.3.1 Government Decree on Limiting Emissions from Large Combustion Plants

Government Decree on Limiting Emissions from Large Combustion Plants was published in 2014 and plants had to comply with the requirements on 1 January 2016. The Decree sets requirements for new, existing and old existing plants. New plants are those for which environmental permit was granted 7 January 2013 or later. Requirements for existing plants are applied plants for which environmental permit was granted on 27 November 2002 or later. Respectively, the requirements for old existing plants are applied to those for which environmental permit was granted before 27 November 2002. (Decree on Limiting Emissions from Large Combustion Plants 936/2014)

Emission limit values for SO_2, NO_2, CO and dust are determined in the Decree on Limiting Emissions from Large Combustion Plants. The limit values are set separately for new and existing plants and for different fuel types. If multiple fuels are used, the ELVs are determined as the sum of weighted ELVs for different fuels. The compliance with ELVs is monitored in periods of hour, day and month. According to the Decree, new plants comply with the emission limits if none of the monthly averages exceeds the ELV, none of the validated daily averages exceeds 110 % of the ELV and 95 % of all the validated hourly averages during the year do not exceed 200 % of the ELV. (Decree on Limiting Emissions from Large Combustion Plants 936/2014)

The compliance rules for existing plants are the same as for new plants, except that monthly averages are not monitored. An old existing plant complies with the limits if none of the monthly values exceed the limits, 97 % of all the validated 48-hour averages of SO_2 and dust and 95 % of all the validated 48-hour averages of NO_2 during the year do not exceed 110 % of the ELVs. Maximum of three hourly averages per day can be invalidated because of malfunction or maintenance of the measuring system in order to calculate valid daily average. The compliance with ELVs is not monitored during start-up and shut-down periods, during breakdown or malfunction of the flue gas purification equipment or during problems with fuel supply. In addition to emission limit compliance reporting, the mass emissions of SO_2, NO_x and dust shall be reported to the ELY centre and the municipal environmental protection authority once a year. (Decree on Limiting Emissions from Large Combustion Plants 936/2014)

Plants eligible for the flexibility mechanisms determined in the IED can comply with less strict ELVs, set according to the LCP Decree 1017/2002. The Transitional National Plan was in force until June 2020. During the period the total emissions of all plants covered by the plan were monitored and they had to comply with the maximum values set in the plan. In total, the TNP covered 119 energy producing units. The limited lifetime derogation mechanism is still in force until the end of 2023 and the total number of energy producing units under the mechanism is 11. Flexibility mechanism for district heating plants is also still valid until the end of 2022 and covers 61 energy producing units in total. Plants are eligible for the mechanism if they deliver at least 50 % of their heat production as steam or hot water to district heating network. (Karjalainen 2016)

3.3.2 **Government Decree on Waste Incineration**

The latest version of the Government Decree on Waste Incineration was published in 2013 and came into force on 10 February 2013. The Decree determines emission limit values for dust, TOC, HCl, HF, SO_2, NOx and CO. These emissions are monitored continuously and the compliance with emission limits is monitored with half-hourly and daily averages. In addition, CO is monitored in 10-minute periods. There are also limits for heavy metals and PCDD/F compounds which shall be measured at least twice a year. According to the Decree, the plant complies with the limits if none of the daily averages exceeds the ELVs, none of the half-hourly averages exceeds the A-limits and 97 % of the half-hourly averages are under the B-limits. For CO, the requirements are fulfilled if 97 % of the daily averages are less than the daily limit, none of the half-hourly averages exceeds the half-hourly limit and 95 % of the 10-minute averages are lower than the 10-minute limit. (Decree on Waste Incineration 151/2013)

Maximum of five hourly averages per day can be invalidated because of malfunction or maintenance of the measuring system in order to calculate valid daily average. The compliance with the ELVs is always monitored when waste is incinerated, including start-up and shutdown periods and periods of breakdown or malfunction of the flue gas purification equipment. When the incineration in the boiler has stopped, the ELVs are not monitored. (Decree on Waste Incineration 151/2013)

3.4 Other Directives

Other EU directives related to emission monitoring are the Medium Combustion Plant Directive, the National Emission Reduction Commitments Directive and the Emission Trading Directive. The directives are briefly described in this chapter, but emission reporting addressed further in this study does not apply to reporting under these directives.

The Medium Combustion Plant (MCP) Directive (2015/2193) regulates emissions from the combustion of fuels in plants with a rated thermal input equal to or greater than 1 MW and less than 50 MW. It fills the regulatory gap of the IED, which covers plants whose capacity is greater or equal to 50 MW. The directive covers around 143 000 MCPs in the EU. MCPs are used for a large variety of applications, including electricity production, residential heating and cooling and providing heat or steam for industrial processes. The MCPD regulates SO_2, NO_x, and dust emissions to air. Also, monitoring of CO is required. Compliance with the emission limits is ensured by periodic measurements. For new plants, the emission limit values have been in force from 20 December 2018. For existing plants, the limits will come to force in 2025 or 2030, depending on the size of the plant. There are flexibility mechanisms for district heating plants and biomass firing. (European Commission 2020d)

The National Emission Reduction Commitments Directive (2016/2284) is part of the EU's long-term program to achieve a level of air quality that does not cause significant negative impacts to human health and nature. The directive sets national emission reduction commitments for five main air pollutants: NO_x, SO_2, volatile organic compounds, particulate matter and NH_3. The directive entered into force in 2016 and defines pollution levels for 2020-2029 and from 2030 onwards. The national reduction commitments are defined as reduction percentage compared to the nation's emission levels in 2005. Member States must report the emissions covered by the system yearly to the commission in an inventory report. (Directive 2016/2284/EU)

The aim of the Emission Trading Directive (2003/87/EC) is to keep the emissions covered by the EU Emission trading system below an EU-wide target (TEM a). The EU ETS is a 'cap and trade' system, which was set up in 2005. It limits GHG emissions from more than 11 000 heavy energy-using installations and airlines operating between the countries in the scope by setting an EU-wide cap on the total amount of certain GHG emissions that can be emitted by the installations. The system covers around 45 % of the EU's greenhouse gas emissions. Companies within the scope receive or buy emission allowances, which they can trade among other companies. Operators must submit an emission report each year and surrender enough allowances to cover the emissions they emitted during the year. (European Commission 2015) In the energy industry, the ETS concerns CO_2 -emissions from plants with thermal power greater than 20 MW (TEM b). Since GHGs are included in the ETS, they are excluded from the monitoring under IED. Consequently, environmental permits prepared based on IED do not set limit values on GHGs. An exception to this is N_2O, the monitoring of which is required by the BREFs.

3.5 Future

On December 2019, European Union presented a new climate strategy called the European Green Deal, which aims for climate neutrality in the EU by 2050. To support the Green

Deal's strategy goals, the European Commission is committed to review the IED. As a part of the work, an evaluation of the IED was done in 2020. The evaluation concluded that the directive has played an important role in reducing emissions to air, but improvements could be made in its design and implementation. The directive could have greater contribution to decarbonization and the circular economy. The Commission has started to work on an impact assessment and will make a legislative proposal for revision of the IED at the end of 2021. The impact assessment will define the problems to be tackled, identify options to address them and assess the impacts of those options. (European Commission & Ricardo 2020, 13-14) The impact assessment contains six problem areas, which are presented in the Figure 11.

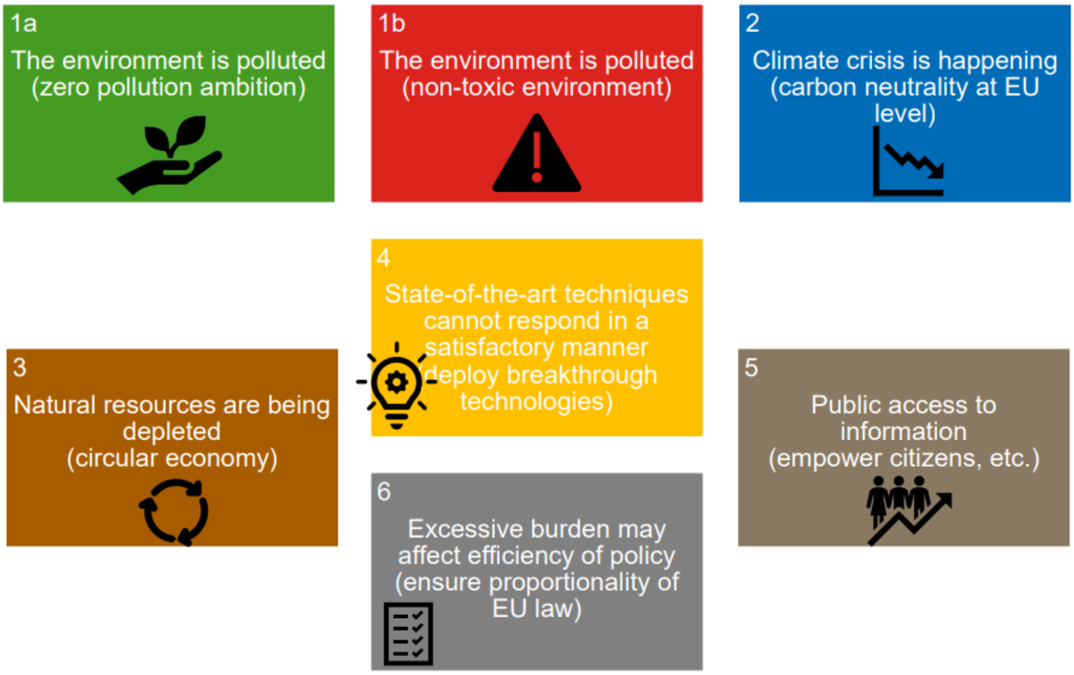


Figure 11. Problem areas under consideration in the impact assessment. (European Commission & Ricardo 2020, 16)

The first problem area takes into consideration problems regarding environmental permitting and emissions monitoring. Permitting processes and enforcement of the permits currently lack clarity and guidance, including the implementation of BAT conclusions. For instance, Member States often have different interpretations of the compliance assurance rules with emission limit values. Also, practices related to monitoring of environmental permits vary across the States. There are different interpretations of how the measurement uncertainty shall be taken into account. In addition, the latest available technique, real-time reporting of emission data, is used limitedly. Real-time reporting would improve transparency and the problems regarding the fifth problem area: public access to information. Hence, the assessment considers provisions to integrate real-time emission data to Member States' databases. (Ricardo 2021, 18-21)

The second problem area addresses carbon neutrality at EU level. GHG emissions from installation within the EU ETS are not regulated by the IED. However, a number of IED installations are not included in the monitoring under the EU ETS and thus their CO_2 emissions are not monitored at all. Also, GHGs other than CO_2 are emitted from combustion plants, most of which are not regulated by the ETS. An estimation is that around 10 % of GHG emissions from IED plants are not covered by the ETS, which represents about 4 % of total EU GHG emissions. (European Commission 2020b, 5) Options to solve the issue are examined in the impact assessment. Possible options include defining directly binding GHG emission limits and/or energy efficiency standards in the IED or setting BAT-based GHG emission limits. (European Commission & Ricardo 2020, 30)

The sixth problem area addresses internally conflicting regimes of the IED. Currently both the IED and the BAT conclusions set requirements for LCPs and WI plants. Compliance assessment of these plants is complicated because the averaging periods for emission limit monitoring differ. In addition, terminology related to normal operating conditions is undefined. The assessment study considers options to rationalize the requirements and to clarify the terminology. (Ricardo 2021, 39)

In addition to the revision of the IED, a revision of the LCP BAT conclusions is expected. In January 2021, the Court of Justice of the European Union annulled the conclusions due to an appeal brought by the Republic of Poland. New BAT conclusions shall be adopted within 12 months from the delivery of the judgement and the existing ones may be maintained until the new act enters into force. (European Commission 2021) Practical consequences of the judgment can vary and are difficult to predict. It is possible that the new act will be adopted with the same contents as the annulled one. However, if Member States do not agree on the contents, there is a risk that the conclusions will not be adopted in time, and there will no longer be valid conclusions after 22 January 2022. (CMS 2021)

4 CONTINUOUS EMISSION MONITORING SYSTEMS

A continuous emission monitoring system (CEMS) is required for monitoring and reporting emissions on a continuous basis. A CEMS consists of a sampling interface, emission analyzers and a system which receives and handles the emission data. Two major methods for continuous sampling are extractive and in-situ system. An extractive system extracts and conditions the gas before entering the analyzer, whereas in-situ analyzers measure the gas directly in the stack. (Jahnke 2000, 2-3) A measuring system installed permanently to a site for continuous emission monitoring is called an Automated Measuring System (AMS).

Data acquisition and handling system (DAHS) receives the emission data from the AMS and converts the data to appropriate units, calculates required parameters, compares them to emission limit values and provides reports for both internal and external use. The DAHS can receive measurement data in analogue (e.g. current) or digital form directly from an AMS, via a digital bus system (e.g. Modbus) or from a Distributed Control System (DCS). Even though regulations are driving force for emission monitoring, the emission data is also valuable in process control and optimization. (CEN 2020a, 4; Jahnke 2000, 3) The continuous emission monitoring process is described in Figure 12.

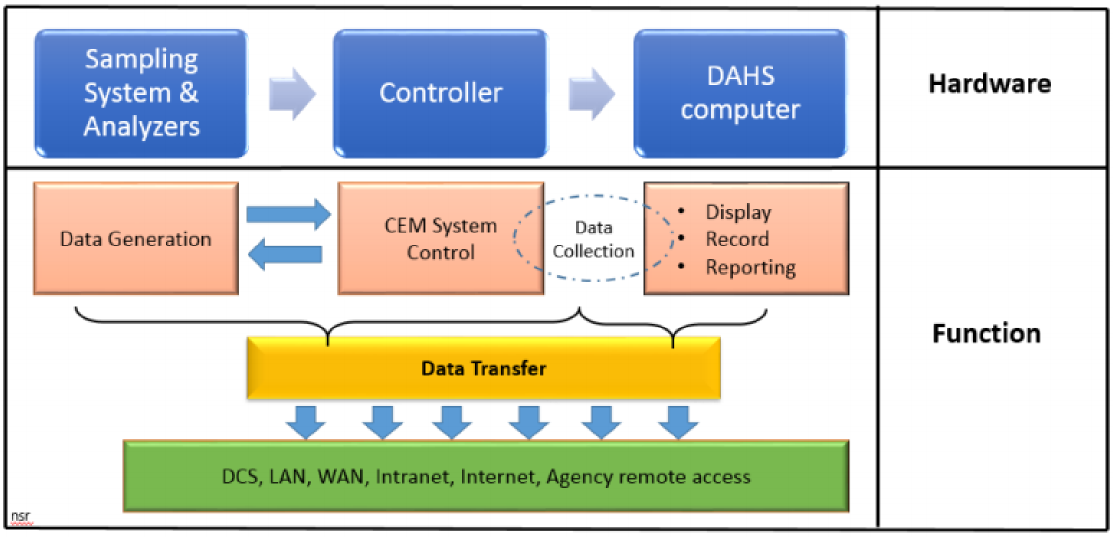


Figure 12. Continuous emission monitoring process and functions (Department of Environment Malaysia 2019, 33).

The chapter 4.1 introduces common emission analyzers used in automated measuring systems and the chapter 4.2 addresses quality assurance of automated measuring systems. The uncertainty of the measurements is discussed in the chapter 4.3. The chapter 4.4 addresses the requirements for data acquisition and handling systems. Finally, the last chapter 4.5 introduces the Valmet DNA Emission Monitoring and Reporting System.

4.1 Emission Analyzers

A wide range of analytical methods can be used for emission measuring. The most common techniques for continuous measurements are Infrared Spectroscopy (IR) and Fourier Transform Infrared Spectroscopy (FTIR). IR technique is based on the ability of different gases to absorb infrared radiation at a specific wavelength. The analyzers using IR technique are divided into two groups: dispersive and non-dispersive analyzers. The non-dispersive analyzers usually measure one component whereas dispersive analyzers can measure multiple components at the same time. An example of a dispersive analyzer is the FTIR analyzer. (VTT 2007, 28). The working principle of an FTIR analyzer is shown in Figure 13.

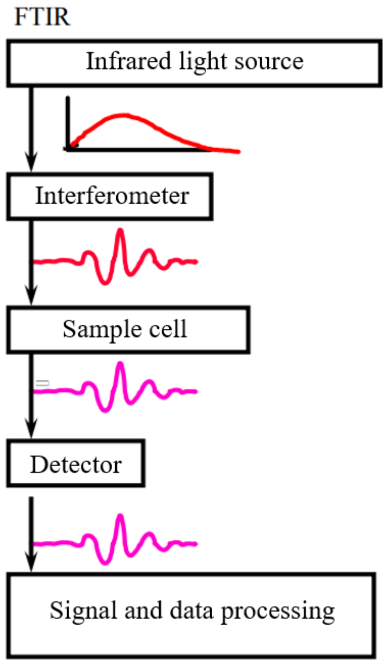


Figure 13. The operating principle of an FTIR analyzer (Modified from source: VTT 2004, 16).

The interferometer separates the infrared light into its different wavelengths. The modulated infrared light then goes through the sample cell which absorbs infrared light at certain wavelengths. The unabsorbed light continues to a detector which produces an electronic signal. An absorption spectrum is obtained from the signal by Fourier transform. The spectrum is analyzed qualitatively to reveal the components present in the gas. (VTT 2004, 16).

Wide range of components, including CO, CO_2, NO_x, SO_2, HCl, HF, NH_3 and different organic compounds can be measured with an FTIR analyzer. Of the typically measured gas components, only oxygen requires a separate analyzer. An advantage of the technique is that the flue gas does not have to be dried before the analysis. Respectively, a disadvantage of the IR technique is that some compounds absorb infrared radiation at the same wavelength. For example, H_2O and CO_2 in the flue gas disturb the measurement of CO. (VTT 2007, 29) Typically, hot extractive sampling is used with an FTIR analyzer (VTT 2004, 18).

In addition to IR techniques, there are several other techniques too. Chemiluminescent detector can be used to measure nitrogen oxides. It is based on the reaction between nitrogen monoxide and ozone, which produces infrared light of a certain wavelength. Ultraviolet fluorescence is the most common method for measuring SO_2. Its technique is based on the fluorescence of SO_2 due to absorption of ultraviolet energy. Several components, such as O_2, CO, SO_2 and NO_x can be measured with an electrochemical sensor, which is based on the inherent reduction-oxidation reaction of each component. Dust emissions can be determined, for example, with gravimetric analysis. Flame ionization detector can be used to detect total organic carbon emissions. (VTT 2007, 30-36).

The most common measuring techniques for mercury are cold-vapor atomic absorption spectroscopy and cold-vapor atomic fluorescence spectroscopy. Mercury appears in oxidized (Hg^{2+}), elemental (Hg^0), or particulate-bound (Hg_p) form in the flue gas. However, analyzers can only detect elemental mercury. Hence, the other two forms need to be converted to their elemental form by acid or thermo-reductive treatments before the measurement. (Pandey et al 2011, 914)

In addition to flue gas components, some peripheral parameters need to be measured in order to convert emission data to specified conditions. Such parameters are for instance concentration of water vapour, temperature and pressure. If mass emissions are to be calculated, also flue gas flow rate must be measured. Thermoelement and pitot tube are commonly used for the determination of the process values. (VTT 2007, 11, 16).

4.2 Quality Assurance of Automated Measuring Systems

Data quality is the most critical aspect in reliable emission monitoring (European Commission 2018, 17). The standard *EN 14181 Stationary source emissions. Quality assurance of automated measuring systems* defines procedures for assuring that an AMS meets the requirements defined in legislation, e.g. EU Directives. The latest version of the standard was published in 2014. Data acquisition and handling systems are excluded from the scope of the standard and covered by the standard series EN 17255, which is introduced in the chapter 4.4. The limits for the Quality Assurance (QA) of the AMS are shown in Figure 14.

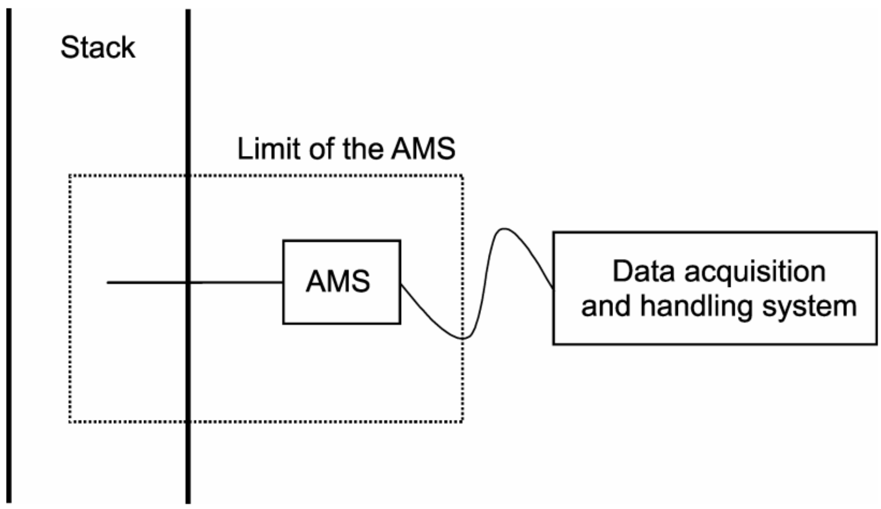


Figure 14. Limits for the QA of the AMS. (CEN 2014, 13)

In order to fulfill the requirements set by the standard, three different Quality Assurance Levels (QAL) and an Annual Surveillance Test (AST) are needed. The first quality assurance level (QAL1) is described in the standards EN 15267-3 and EN ISO 14956. The QAL1 procedure evaluates the AMS's suitability for its measuring task and describes a method for the calculation of total uncertainty of the measured values. (CEN 2014, 4)

The second quality assurance level (QAL2) procedure is used to determine the AMS's calibration function and its valid range with parallel measurements with a standard reference method. In addition, the variability of the measurement results obtained by the system is defined and compared to the maximum permissible uncertainty defined in regulations. QAL2 includes also a functional test which ensures that the installation and measurement site fulfill their requirements. QAL2 shall be performed at least every 5 years or more frequently if required in legislation or by a competent authority. QAL2 must be performed additionally if there is a major change in the plant operation or in the measuring system, which affects the measurement results significantly. The QAL2 is carried out by a testing laboratory. (CEN 2014, 12-15) The validity of the calibration range must be evaluated by the plant owner on a weekly basis. QAL2 shall be performed if either of the following conditions is true:

- more than 5 % of the measured values during a week are outside the valid calibration range for more than 5 weeks in the period between two AST;
- more than 40 % of the measured values during a week are outside the valid calibration range for one or more weeks. (CEN 2014, 22)

In the third quality assurance level (QAL3) the AMS is evaluated during its normal operation. The target of the test is to maintain the quality of the AMS so that the measured values meet the required uncertainty on a continuous basis. The test is done by periodic zero and span checks which indicate the change in measured values caused by drift of the measurement device. With the use of control charts, e.g. CUSUM control chart, the drift and change of precision are then compared to the values obtained in QAL1. The procedure identifies whether maintenance of the AMS is necessary. The plant owner is responsible for the implementation of the QAL3 procedures. (CEN 2014, 25)

The annual surveillance test evaluates whether the AMS functions correctly and if the calibration function and variability have remained as determined in the QAL2. The first part of the AST is the same functional test as carried out in the QAL2. In the second part, the validity of the calibration function and the precision of measurements are evaluated by comparing the measured values to parallel measurements with the standard reference method. The valid calibration range may be increased according to the results. The AST shall be performed by a testing laboratory (CEN 2014, 30-31) The whole quality assuring process is described in Figure 15.

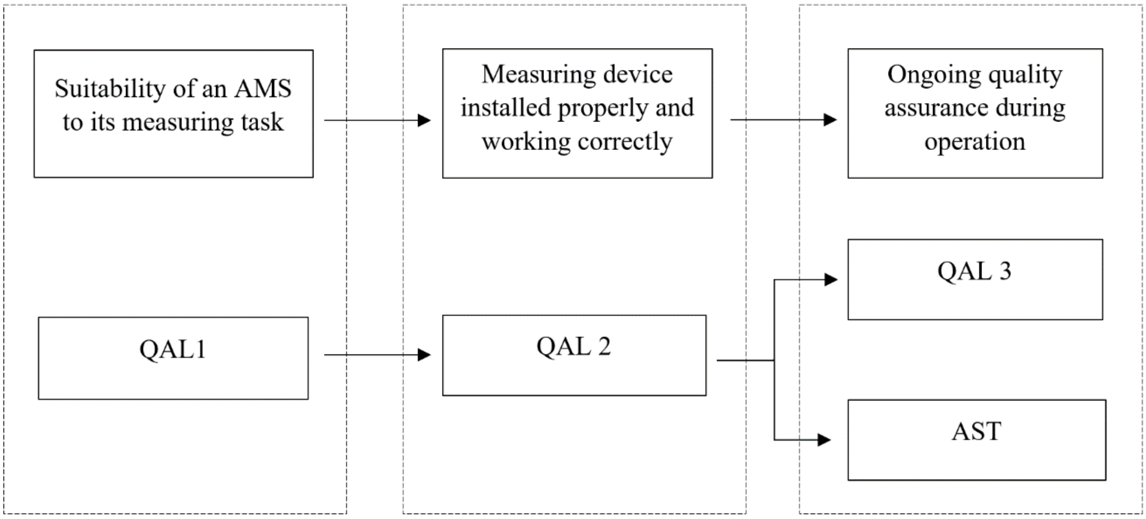


Figure 15. Quality assurance of an AMS (Modified from source: Pellikka 2019, 2).

4.3 Uncertainty of the Measurements

A measurement result is always an approximate value which can contain systematic and accidental errors. Systematic error appears as a constant and it can be eliminated with regular calibration. Accidental errors occur due to changes in measuring environment and they can be decreased with parallel measurements. (VTT 2007, 53) An analyzer manufacturer usually reports the uncertainty of the results as a sum of the systematic error and the relative uncertainty. The systematic error depends on the measuring range and the relative uncertainty varies according to the magnitude of the measured value. (Hiltunen et al 2011, 39) Regulations define the maximum permissible uncertainty of the measurements. The quality assurance procedures discussed in the chapter 4.2 assure that an analyzer fulfills the requirements and that the requirements are also met during its operation.

The BAT Reference Documents do not specify how the uncertainty of the measurements shall be considered when comparing measurement results to emission limit values. However, the IED defines that the measurement uncertainty in the form of 95 % confidence interval should be subtracted from the measurement average values. Different interpretations of this can be presented in national legislation. The most common approach is to subtract the uncertainty from the measured average and to use the resulting value for further assessment. The subtraction of the uncertainty from the measured average may lead to negative results and therefore, some Member States, such as Austria, advise to handle such data by setting the result to zero. (European Commission 2018, 25)

For large combustion plants the measurement uncertainties, representing the 95 % confidence interval, are

- Carbon monoxide (CO) 10 %,
- Sulphur dioxide (SO_2) 20 %,
- Nitrogen oxides (NO_x) 20 %,
- Dust 30 %. (Directive 2010/75/EU)

The IED does not define uncertainty values for ammonia (NH_3) and Mercury (Hg). However, the Finnish guidance document for the application of the LCP BREF advices to use 40 % for the both substances. (Novox 2018, 22) According to the Decree on large combustion plants, the validated hourly averages shall be calculated by multiplying the uncertainty percentage with the emission limit value and subtracting it from the measured value. The validated daily averages are calculated from the validated hourly averages. (Decree on Limiting Emissions from Large Combustion Plants 936/2014)

The percentages for waste incineration are

- Carbon monoxide (CO) 10 %,
- Sulphur dioxide (SO_2) 20 %,
- Nitrogen dioxide (NO_2) 20 %,
- Dust 30 %,
- Total organic carbon (TOC) 30 %,
- Hydrogen chloride (HCl) 40 %,

- Hydrogen fluoride (HF) 40 %. (Directive 2010/75/EU)

As for LCPs, the IED does not specify the uncertainty values for ammonia (NH_3) and Mercury (Hg). The uncertainty value 40 %, defined in the Finnish guidance document for the application of WI BREF, can be used. (Ministry of the Environment 2019, 11) According to the Decree on waste incineration, the validated 10-minute and half-hourly averages shall be calculated by multiplying the uncertainty percentage with the emission limit value and subtracting it from the measured value. Validated daily averages are calculated from the validated 10-minute and half-hourly averages. (Decree on Limiting Emissions from Large Combustion Plants 936/2014)

4.4 Requirements for Data Acquisition and Handling Systems

The European standard series EN 17255 specifies minimum requirements for data acquisition and handling systems of stationary emission sources. It consists of four parts:

- *EN 17255-1 Part 1: Specification of requirements for the handling and reporting of data (2019),*
- *EN 17255-2 Part 2: Specification of requirements on data acquisition and handling systems (2020),*
- *EN 17255-3 Part 3: Specification of requirements for the performance test of data acquisition and handling systems (draft),*
- *EN 17255-4 Part 4: Specification of requirements for the installation and on-going quality assurance and quality control of data acquisition and handling systems (proposal).*

The first and the second part of the series has been published, the third part is currently under evaluation and the fourth part has been proposed. Before the standard series, there were no international regulations on DAHSs. Therefore, the reported values were dependent on algorithms installed on the DAHS. The standard series unifies the emission calculations and ensures that the reported values are consistent. It also specifies performance specifications, quality assurance and quality control requirements and requires certification. (Becker) Figure 16 shows the elements and functionalities of the DAHS that are defined in the standard series.

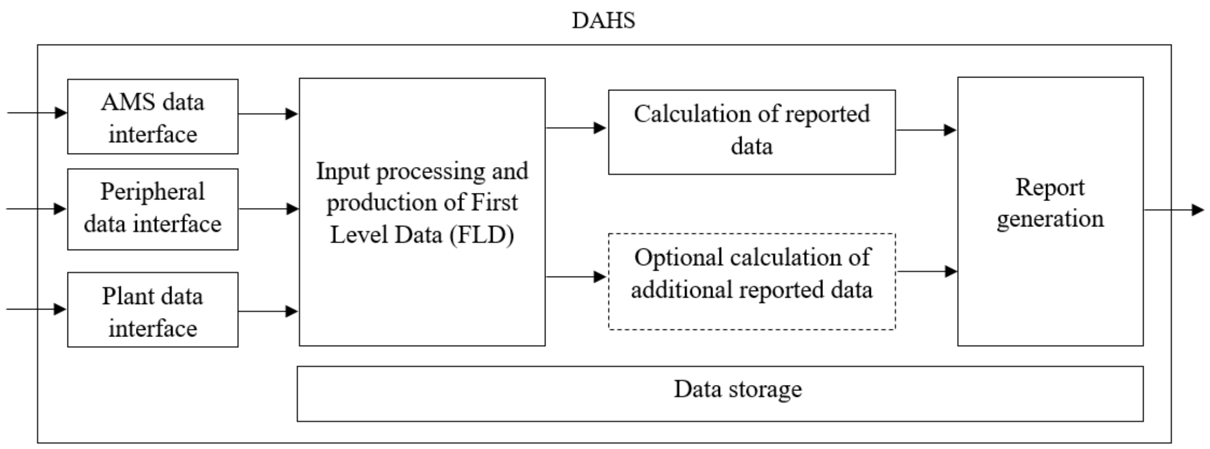


Figure 16. Elements and functionalities of the DAHS. (Modified from source: CEN 2020a, 7)

The first part of the series defines procedures that shall be used for the handling of raw data from AMS to reported values. It specifies calculations to be used in forming of the reported values, such as concentration averages and mass emissions. It also determines minimum requirements for the reports produced by the DAHS. (CEN 2019) The second part specifies the implementation of the first part and specific requirements on the functionality of the DAHS. It specifies performance requirements on

- data acquisition,
- input data processing,
- reported data,
- reports,
- data storage,
- system functions,
- data integrity and
- documentation. (CEN 2020a)

The third part specifies performance tests for the DAHS, including specification of

- test procedures,
- description of laboratory test and
- requirements on the test laboratory. (CEN 2020b)

The fourth part will specify requirements on the installation of the DAHS and quality assurance and control of the DAHS. This study focuses more detailed on the first part of the series. The main principles of calculation, evaluation of the validity of data and reporting requirements of the standard are introduced in the chapters 4.4.1-4.4.3.

4.4.1 Calculation Principles

The standard divides data into three categories: First Level Data (FLD), Short-Term Averages (STA) and Long-Term Averages (LTA). First Level Data is either unprocessed raw data from measurement devices with a scan interval not exceeding 10 s or averages of the raw data over an averaging time not exceeding 1 min. First level data shall be stored in a permanent storage for at least five calendar years. The second level of data, short-term averages, are formed by averaging the FLD over the required period and then applying the QAL2 calibration function to the average. According to the IED, the time period of STA is 1 hour in large combustion plants and 0,5 h or 10 min in waste incineration plants. (CEN 2019, 14, 18)

Standardized Short-Term Averages (SSTA) are calculated by normalizing valid STA values with short-term averages of peripheral data. The following equation shall be used to standardize a mass concentration value:

$$c_{\mathrm{ref}} = c_{\mathrm{m}} \cdot \frac{T_m}{T_{ref}} \cdot \frac{p_{ref}}{p_m} \cdot \frac{100\,\% - h_{ref}}{100\,\% - h_m} \cdot \frac{21\,\% - o_{ref}}{21\,\% - o_m}\,, \qquad (1)$$

where

c_{ref} standardized emission concentration (mg/m^3(n)),

c_{m} measured emission concentration (mg/m^3),

T_{m} (absolute) measured temperature of the gas sampled (K),

T_{ref} (absolute) standard temperature (273,15 K),

p_{m} measured pressure of the gas sampled,

p_{ref} standard pressure (101,3 kPa),

h_{m} measured sample water vapour content (volume fraction) of the gas sampled,

h_{ref} standard water vapour content (0 % at dry conditions),

o_{m} measured oxygen content (volume fraction) of the gas sampled,

o_{ref} standard oxygen content (volume fraction). (CEN 2019, 31-33)

Validated short-term averages (VSTA) are calculated by subtracting the uncertainty from SSTA according to the procedure defined in national legislation. VSTA are used in compliance reporting. (CEN 2019, 21, 23)

Long-term averages can be calculated as block or rolling averages in periods of day, week, month or year. Daily averages are calculated as arithmetic mean of valid VSTA. Other long-term averages are formed as arithmetic mean of valid SSTA with the uncertainty subtracted as defined in national legislation. (CEN 2019, 23)

Mass emissions for a STA period shall be calculated as follows:

$$STA_{\mathrm{PME}} = SSTA_P \cdot SSTA_F \cdot t_{\mathrm{STA}} \ , \tag{2}$$

where

STA_{PME} pollutant mass emission during the STA period,

$SSTA_{\mathrm{P}}$ the SSTA of the pollutant mass concentration,

$SSTA_{\mathrm{F}}$ SSTA of the flow,

t_{STA} the STA period (CEN 2019, 22).

In case that the concentration and flow rate are measured in the same condition, pollutant STA and flow STA can be used instead of the standardized values. Mass emissions of other time periods may be calculated by summation of all the STA mass emission values during the period. (CEN 2019, 22)

4.4.2 Validity and Status of Data

The standard defines how status signals associated to data shall be recorded. These signals concern the operation state of the plant and information of the AMS. Based on the statuses, the standard determines which values shall be used in further calculations and in compliance monitoring with emission limit values. With each FLD, the status of the plant and the status of the FLD shall be recorded. The status of the plant tells whether the plant was in reportable or not in reportable state during the data was measured. Possible states are, for instance, plant operating or in fault or plant in start-up or shutdown mode. Legislation determines which plant states are reportable. The status of the FLD tells whether the data is valid to use in calculation of reportable values. (CEN 2019, 15) The following information of the AMS should be recorded as a minimum for the status of the FLD:

- FLD value outside measurement range (e.g. 4 - 20 mA),
- AMS under functional test (QAL2 or AST),
- AMS performing internal check or QAL3,
- AMS in fault or under maintenance. (CEN 2019, 15)

If any of the raw data used to form the FLD is associated with these statuses, the FLD value shall be flagged accordingly. Data outside the measurement range must be flagged but it does not invalidate the value. Instead, the three other statuses invalidate the FLD and therefore such data shall not be used to form reported data. (CEN 2019, 15)

The status of the STA should contain the same information as the FLD with the following additions:

- contains FLD values with AMS outside the measurement range,
- contains capped FLD values,
- validity of STA (valid, invalid or plant not in reportable state). (CEN 2019, 19)

A competent authority may set an upper limit for the measurement range for digital data transmission and FLD is capped if it is over the limit. The standard recommends that the upper limit is at least 3 times the daily ELV for waste incineration plants and 5 times the daily ELV for large combustion plants. Capped values are treated similarly as values over the measurement range 4 - 20 mA. (CEN 2019, 35)

The validity of STA is determined according to a two-third rule. The flow diagram in Figure 17 demonstrates how the validity of STA is evaluated.

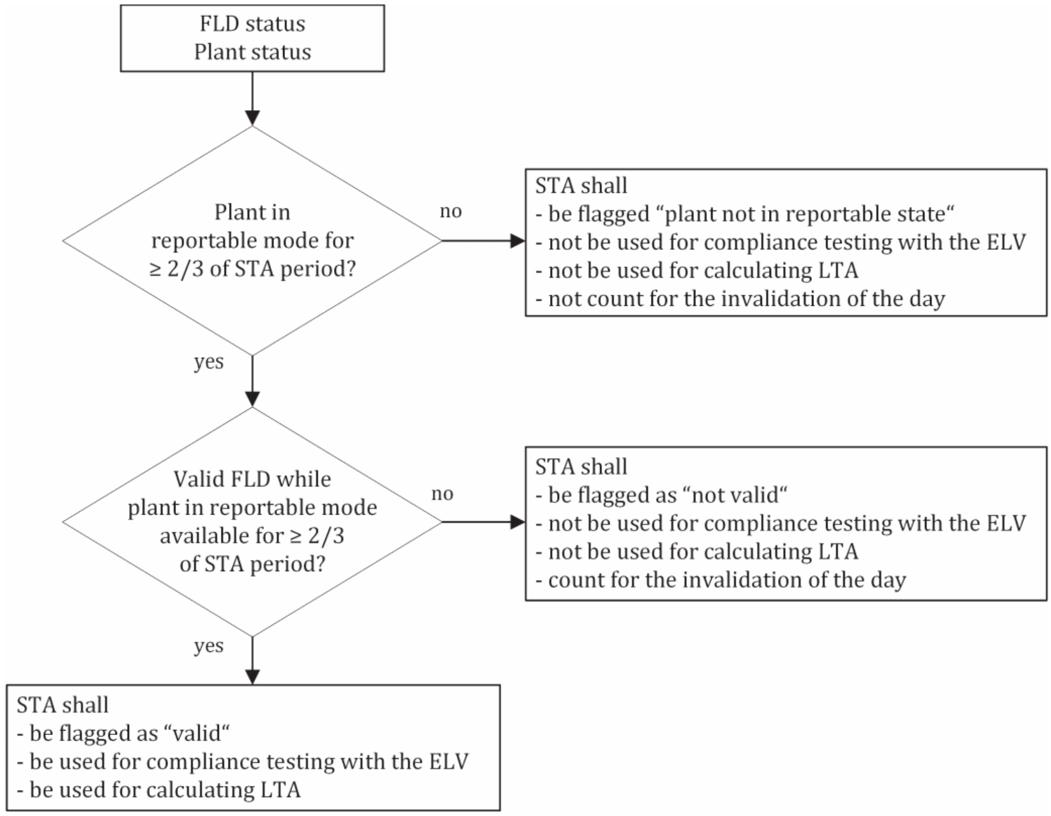


Figure 17. Evaluation of the validity of STA (CEN 2019, 20).

Daily average can be calculated if at least 6 h of the day is valid VSTA. In order to calculate other long-term averages at least 10 % of the LTA period must be covered by valid SSTA. A day shall be invalidated if the number of invalid SSTA periods during the day exceeds the maximum number defined in legislation. According to the IED, for large combustion plants, maximum of three hourly averages can be marked as invalid within a day due to malfunction or maintenance of the measuring system. Respectively, the maximum for waste incineration plants is five half-hourly averages marked as invalid within a day. In such case that the day is invalidated, all the valid STA within that day are used to check the compliance with the regulations. Maximum of 10 invalidated days per year is allowed by the IED. (CEN 2019, 23-24)

The two-thirds rule is not applied for mass emission calculations. Mass emissions shall be calculated with appropriate substitute values if the STA period contains invalid pollutant or flow data. Mass emission calculated with substitute values should be flagged accordingly. (CEN 2019, 24, 29)

4.4.3 Reporting Requirements

According to the standard, daily, weekly, monthly and annual reports shall be produced by the DAHS. There must be separate reports for each measured component and for each reportable mode. Each report should include information on the plant and the emission point, period of the report, pollutants and ELVs. In addition, the standard includes a table of 23 items that should be reported. The standard determines separately for each item in which reports it should be included (daily, weekly, monthly or annual). These items are, for instance, number of STA invalidated, number of VSTA exceeding the ELV, number of invalid days according to legislation, et cetera. Also, there is a new requirement for QAL2 reporting - the percentage of SSTA over the valid calibration range must be monitored in weekly, monthly and annual reports. (CEN 2019, 24-25)

4.5 Valmet DNA Emission Monitoring and Reporting System

Valmet Automation provides multiple solutions for emission monitoring and reporting. The solutions produce information needed for emission reporting to authorities and for the plant's own needs. By integration to control system, the solutions can be utilized in active or even proactive emission management. DNA LCP Emission Monitoring is designed for emission monitoring in large combustion plants and respectively, DNA WI Emission Monitoring is designed for emission monitoring in waste incineration plants and waste co-incineration plants. DNA QAL3 Monitoring performs quality assurance of the AMS according to the standard EN 14181. The product scope includes also DNA Eco Diary, which is a tool for increasing environmental knowledge by storing and reporting environmental data. The DNA CO2 Monitoring can be used for carbon dioxide reporting according to the EU Emission Trading Directive. (Valmet a) In this study, the focus is on the LCP and WI Emission Monitoring solutions and their compliance with the latest requirements for emission monitoring and reporting.

The solutions operate on DNA Information Management System, which may be connected to DNA Automation System or other distributed control system. The DNA Information Management System stores and processes real-time data from a DCS for a later analysis. It is based on DNA Historian, which combines process interfaces, calculations and databases into one uniform solution. All the necessary information, such as measurements, device statuses and alarms are stored into history databases. Desired outputs, such as key performance indicators and aggregates (averages, sums etc.), are calculated by the DNA Historian calculation environment. The collected information and calculation results are displayed on reports, which are located in a web-based portal and on operate displays. (Valmet b) An example configuration of the Valmet Emission Monitoring and Reporting System (EMRS) and its functions are shown in Figure 18.

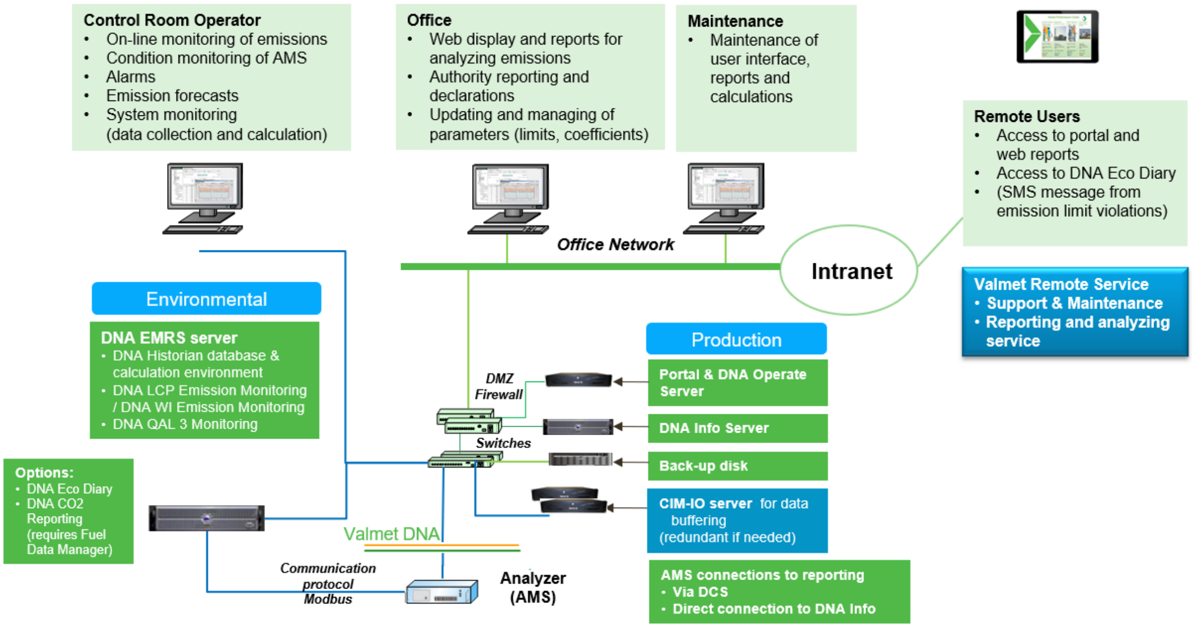


Figure 18. Layout of the Valmet DNA Emission Monitoring and Reporting System.

The LCP and WI Emission Monitoring applications perform concentration (mg/m^3(n)) calculations usually at one-minute level. Average calculations can be performed in 10-minute, half-hourly, hourly, weekly, monthly or yearly periods, depending on the environmental permit of the plant. The QAL2 calibration function is applied to minute values. The measurement device's status (disturbance, maintenance or testing) is also checked and reported for each measured value. The measured values are standardized to reference conditions and oxygen level and the subtraction of 95 % confidence value is done if allowed. In addition to the outputs needed for authority reporting, the applications provide emission forecasts and accumulative and moving averages for effective emission controlling of the power plant. (Valmet a)

The applications produce daily, monthly and annual reports as well as displays for online emission monitoring. The reports display emission concentration averages, concentration trends and mass emissions during different operation modes. The reports mark concentrations as red if they are over the emission limit and show the number of limit exceedances during the period. The reports display also process values, operating times and possible disturbance times of cleaning equipment and measurement devices. Figure 19 shows NO_x emissions sheet from a monthly report.

LCP MONTHLY REPORT (IED) Valmet

11-2020 Plant Printing time: 12/30/2020 1:47 PM

NOx

Hourly limit value (200 %) 500 mg/m³(n) | Daily limit value (110 %) 275 mg/m³(n) | Monthly limit value 250 mg/m³(n)

Day	Daily Average mg/m³(n)	Hourly Exceedings -	Normal Operation t	Start-up/ Shutdown t	Cleaning Equipment Malfunction t	Measuring System Malfunction t	Total t
01	73.5	0	1.14	0.00	0.00	0.00	1.14
02	73.4	0	1.14	0.00	0.00	0.00	1.14
03	73.6	0	1.15	0.00	0.00	0.00	1.15
04	73.4	0	1.14	0.00	0.00	0.00	1.14
05	73.6	0	1.15	0.00	0.00	0.00	1.15
06	73.3	0	1.14	0.00	0.00	0.00	1.14
07	73.6	0	1.15	0.00	0.00	0.00	1.15
08	73.7	0	1.15	0.00	0.00	0.00	1.15
09	73.7	0	1.15	0.00	0.00	0.00	1.15
10	73.6	0	1.15	0.00	0.00	0.00	1.15
11	73.1	0	1.14	0.00	0.00	0.00	1.14
12	73.4	0	1.14	0.00	0.00	0.00	1.14
13	73.2	0	1.14	0.00	0.00	0.00	1.14
14	72.7	0	1.14	0.00	0.00	0.00	1.14
15	73.4	0	1.14	0.00	0.00	0.00	1.14
16	73.8	0	1.15	0.00	0.00	0.00	1.15
17	73.5	0	1.15	0.00	0.00	0.00	1.15
18	73.4	0	1.14	0.00	0.00	0.00	1.14
19	73.4	0	1.14	0.00	0.00	0.00	1.14
20	73.8	0	1.15	0.00	0.00	0.00	1.15
21	73.4	0	1.14	0.00	0.00	0.00	1.14
22	73.9	0	1.15	0.00	0.00	0.00	1.15
23	73.2	0	1.14	0.00	0.00	0.00	1.14
24	73.8	0	1.15	0.00	0.00	0.00	1.15
25	73.6	0	1.15	0.00	0.00	0.00	1.15
26	73.1	0	1.14	0.00	0.00	0.00	1.14
27	73.5	0	1.14	0.00	0.00	0.00	1.14
28	73.7	0	1.15	0.00	0.00	0.00	1.15
29	73.5	0	1.14	0.00	0.00	0.00	1.14
30	74.1	0	1.15	0.00	0.00	0.00	1.15
Average	73.5						
Sum		0	34.33	0.00	0.00	0.00	34.33
Minimum	72.7	0	1.14	0.00	0.00	0.00	1.14
Maximum	74.1	0	1.15	0.00	0.00	0.00	1.15

red!	Daily concentration value exceeds 110% of the limit value or monthly value exceeds the limit value
0,0'	Uncertainty substraction sets concentration value to zero
INVALID	Not enough valid data for calculating concentration mean value

Figure 19. NO_x emissions sheet in monthly report.

The applications produce a separate report for QAL2 calibration function validity monitoring. The applications check the calibration function's validity hourly and calculate the percentual excess of the upper limit of the calibration function on a weekly level. The QAL2 report displays the weekly percentual exceeding for each week after the last QAL2 or AST. The report shows also the number of weeks with more than 5 % and more than 40 % of the measured values exceeding the valid calibration function after the last QAL2 or AST.

The most important emission and process information is shown on emission displays. There are web-based emission displays, which can be found from the same portal as the emission reports and operate displays, which can be monitored in the control room. Figure 20 demonstrates an example configuration of a web-based emission display.

Figure 20. Web-based emission display.

Valmet's environmental solutions fulfill the criteria of the IED and are also configurable to meet the plant's environmental permit. Due to configurability and flexibility to add different calculations and functionalities to the solutions, different local and national requirements can be met. The solutions can be configured for different kind of production unit setups, such as when there is a common chimney for two boilers. The solutions also meet the requirements of standards mentioned in legislation, i.e. the EN 14181: Quality Assurance of

AMS. (Valmet 2019) The solutions have been developed in close cooperation with Finnish authorities and power plants (Valmet a). As a part of this study the LCP and WI Emission Monitoring applications are evaluated against the new requirements discussed in the chapter 5 and updated where necessary. The compliance evaluation is in the chapter 6.

5 DISCUSSION ON RECENT REQUIREMENTS FOR EMISSION MONITORING AND REPORTING

This chapter addresses the updated BAT Reference Documents for large combustion plants and waste incineration and the standard EN 17255-1 for data acquisition and handling systems. As a part of the study, discussions with the Finnish ministry of the environment, regional state administrative agency and the centre for economic development, transport and the environment (ELY centre) were conducted. The aim of the discussions was to clarify implementation of the new requirements as well as to find out local interpretations. Also, an operator survey was conducted in order to find out the operators' views on the requirements.

Discussion on the updated LCP and WI BAT Reference Documents is in the chapter 5.1 and discussion on the standard EN 17255-1 is in the chapter 5.2. The results of the operator survey are presented in the chapter 5.3.

5.1 Updated LCP and WI BAT Reference Documents

The updated LCP BREF enters into force in August 2021, whereas the updated WI BREF enters into force two years later, in 2023. Applying the updated BAT conclusions to emission monitoring and reporting systems alongside existing legislation may not be unambiguous. This study identified three main issues regarding the implementation. The issues concern monitoring of the emission limit values defined in the IED alongside of the BAT-associated limit values and identification and reporting of OTNOC situations. The issues are aimed to be clarified based on the discussions with authorities and Finnish guidance documents on the application of the conclusions. There are two guidance documents for LCPs: *Guidance on the application of BAT conclusions for large combustion plants (Ministry of the environment 2017)* and *Technical guidance on the application of BAT conclusions for large combustion plants (Novox 2018)*, and one document for WI plants: *Guidance on the application of BAT conclusions for waste incineration (Ministry of the environment 2019)*.

The first issue concerns how the emission limit values set in the IED shall be monitored when the BAT conclusions come into force. The guidance documents for LCPs and WI plants state that the BAT ELVs do not replace the IED ELVs (Novox 2018, 20; Ministry of the environment 2019, 10). However, the documents do not state how monitoring of the both ELVs shall be performed in practice. The monitoring periods of the BAT ELVs are partly different than the monitoring periods of the IED ELVs. The monitoring periods are shown in Table 1.

Table 1. Monitoring periods of the ELVs.

Limit Monitoring Period	**IED (LCP)**	**LCP BAT**	**IED (WI)**	**WI BAT**
Half-hourly			x	
Hourly	x			
Daily	x	x	x	x
Monthly	x			
Annual		x		

According to the discussions with authorities, IED ELVs and BAT ELVs shall always be monitored simultaneously in normal operation. It should be shown in the reports delivered to authorities, that the both ELVs are complied. In general, the BAT ELVs are more stringent than the IED ELVs (Novox 2018, 9). Hence, it should be adequate to monitor only the BAT ELVs in overlapping monitoring periods. However, the IED ELVs are effective in some operating situations in which the BAT ELVs are not effective. Comparison of the limits' effectiveness in LCPs is presented in the Table 2 and the comparison in WI plants is presented in the Table 3.

Table 2. Emission limit effectiveness comparison in LCPs.

Operation mode	**IED limits (LCP)**	**LCP BAT limits**
Normal operation	Effective	Effective
OTNOC (Start-up, shutdown, cleaning equipment malfunction, fuel availability problem, accident)	Not effective	Not effective
Other OTNOC	Effective	Not effective

Table 3. Emission limit effectiveness comparison in WI plants.

Operation mode	**IED limits (WI)**	**WI BAT limits**
Normal operation	Effective	Effective
OTNOC when waste is not incinerated	Not effective	Not effective
OTNOC when waste is incinerated	Effective	Not effective

As presented in the Table 2 and the Table 3, only the monitoring under the IED shall be performed in certain OTNOC. The EMRS must be able to exclude emissions during OTNOC from BAT compliance monitoring. Thus, there must be different calculations for concentration averages used in compliance monitoring with the IED and the BAT limit values.

The second issue concerns the definition of OTNOC. The BAT conclusions do not determine specifically what kind of situations can be considered as OTNOC. The LCP BREF contains an example list of possible OTNOC, whereas WI BREF does not contain such list. Therefore, OTNOC can be of a large variety of situations. However, these situations should be rare, and the majority of plant's operation cannot be OTNOC. OTNOC are not always unambiguous and therefore it is possible, that unexpected situations happen, which are not listed in the environmental permit. In such cases, the situation shall be reported to the ELY centre, which evaluates, whether the situation can be approved as OTNOC. (Novox 2018, 19; Ministry of the environment 2019, 12)

If unexpected OTNOC and situations that cannot be detected from the automation happen, the emission concentration calculations must be recalculated. Recalculation is needed, because concentration values measured during OTNOC must be ignored from calculations used in compliance monitoring. The same applies for IED limits in certain OTNOC, which are presented in the Table 2 and Table 3. However, most of the OTNOC, in which the IED limits are not effective, can be detected from the automation. For example, start-ups, shutdowns and cleaning equipment faults are such situations. However, the conditions for these situations must be predefined in the automation.

The last issue addressed in this study is how reporting of OTNOC shall be implemented. The BREFs determine that OTNOC events shall be reported to authorities but lack guidance on how the reporting shall be implemented in practice. The Finnish guidance document on the application of LCP BREF suggests that the information of OTNOC situations shall be reported to a competent authority for example in annual reporting (Novox 2018, 31). According to the discussions with the authorities, there are no national instructions on how the reporting should be implemented in practice and thus the implementation may be agreed between the operator and the local ELY centre. According to the discussions, each OTNOC event’s duration, cause and mass emissions should be included in reporting. There should also be a note whether the situation is included in monitoring under the IED.

5.2 EN 17255-1: Specification of Requirements for the Handling and Reporting of Data

The discussions with the authorities clarified that the standard EN 17255-1 is not yet included in legislative requirements in Finland. It is not clear when it will be included and whether there is going to be a national interpretation. Based on emission monitoring projects carried out by Valmet Automation, the standard is already required to be implemented to new DAHSs in some Member States of the EU. Therefore, it is expected that it will soon be required in Finland as well. However, the standard series will not be complete until the fourth part is published, so it is possible, that other parts will not need to be implemented before then. This chapter includes discussion on the requirements of the first part of the standard series, mainly related to the standard’s calculation procedures, mass emission calculations and the reporting requirements.

One of the tasks of this study was to find out what kind of impact the calculation procedures and validation rules of the standard have on calculation results. The standard defines that standardization of the measured emission values is done to half-hourly or hourly values. In Finland, a generally accepted method has been to standardize minute values and to calculate half-hourly and hourly averages based on them. Also, the validation rules of the standard differ to those that have been used. According to the standard, at least two-thirds of the hour or half an hour must be normal operation in order to calculate the concentration. In Finland, one interpretation has been that all the minutes of normal operation should be included in emission reporting.

Application of the two-thirds rule would simplify emission calculations but also affect the accuracy of the results. For example, if an LCP is starting up and less than 2/3 of the hour is normal operation, the hourly concentration is set to zero. In such case, the rule ignores possible high emissions after a start-up. However, if the start-up lasts 1/3 or less of the hour, the concentration is calculated based on all the minute values during the hour, meaning that the minute values during start-up are not excluded. This can result in high concentrations if emissions during start-up are higher than normally. However, if the plant's operation is mostly normal, the rule should not significantly affect the results in the long term.

Other validation rules of the standard are the rules for calculation of daily average and other long-term averages. According to the standard, the daily average can be calculated if the day contains at least 6 h of normal operation and other long-term averages can be calculated if they contain at least 10 % of normal operation. On one hand, the rules prevent occasions where a plant operates only a short time of a period and must report its emissions to authorities. On the other hand, significant emissions may be ignored. The practical effect of the validation rules and the calculation principles is analyzed in the chapter 6.1.

The standard requires mass emissions to be reported as one total value in annual reporting. The standard does not advice to differentiate mass emissions for multiple operation modes. However, it states, that if legislation demands to do so, mass emissions should be calculated for multiple operation modes as if it was one operation mode. For example, if mass emission were to be calculated during start-up, shutdown and normal operation, the calculation should include all these modes but produce only one total value. According to the standard, this would prevent STA and the resulting mass emissions to be discarded during transitions between reportable modes due to the two-thirds rule. (CEN 2019, 24)

On the other hand, the standard states that the two-thirds rule is not applied for mass emission calculations. If mass emissions were calculated only during normal operation, it is not clear, whether one valid minute value of reportable mode would be enough to calculate the STA and the resulting mass emissions. In Finland, there have been emission limit values for mass emissions e.g. during abatement equipment faults. If the principles of the standard were to be implemented, such monitoring could not be performed in the future. The standard contradicts also with the LCP and WI BAT conclusions, which require emissions during OTNOC to be reported. In the discussions with the authorities, it was interpreted that the requirement is met by reporting mass emissions.

The standard advices to apply QAL2 calibration function to STA value. However, it mentions that the application of QAL2 to FLD values does not affect the result. (CEN 2019, 18) In case of parallel AMS, the application of QAL2 to STA may be impossible, since the minute values used in the STA calculation could be measured with either of the AMS. Thus, it is practical to apply the calibration function on FLD level. The standard also introduces new reporting requirements for QAL2 that have not previously been included in legislation. The percentage of SSTA exceeding the valid calibration range should be reported in weekly, monthly and annual reports. There are also several other reporting requirements that require modifications to reporting systems. Therefore, it is important that their necessity outweighs the effort needed for the modifications.

The standard suggests that handling and reporting of data is best performed in a dedicated DAHS. It does not preclude the use of other options as long as they meet all the requirements of the standard series, particularly in relation to speed, accuracy, access, security and validation. (CEN 2019, 4) There are some downsides in separating the DAHS from the plant’s control systems. If real-time data of the DAHS is connected to a control system, it can be utilized in active emission management. That way limit exceedances and harmful environmental impacts can be better avoided. The second part of the standard series specifies requirements for tamper-proof data transfer and handling, so the authenticity of data is ensured in DAHSs.

As stated, there are some ambiguities in the requirements of the standard and interpretations are still needed. However, it is the first standard to regulate DAHSs and therefore its implementation is important in harmonization of emission monitoring in the EU. Currently, the procedures and validation rules of emission calculations may vary significantly between

Member States and even individual DAHSs. An EU-wide guidance document would help to ensure effective and coherent implementation of the standard. However, it is more likely that interpretations will be done in national level.

5.3 Operator Survey

As a part of the study, a short survey was conducted for operators in Finland. The survey included two sections, of which the first part concerned the LCP and WI BAT conclusions and the second part concerned the standard EN 17255-1. The survey was sent by email to 18 power plants that use the Valmet EMRS for emission monitoring and reporting. As a total, 9 answers were received. The respondents were mostly environmental managers of large combustion plants. In this chapter, the most important results of the survey are discussed.

The first part of the survey included questions on the clarity of BAT conclusions and its emission limit values in relation to emission limit values of the IED. The first question was: “Is the content and concept of the BAT conclusions clear to you?”. The scale was from 4 to 1, in which 4 was clear and 1 unclear. The results are shown in Figure 21.

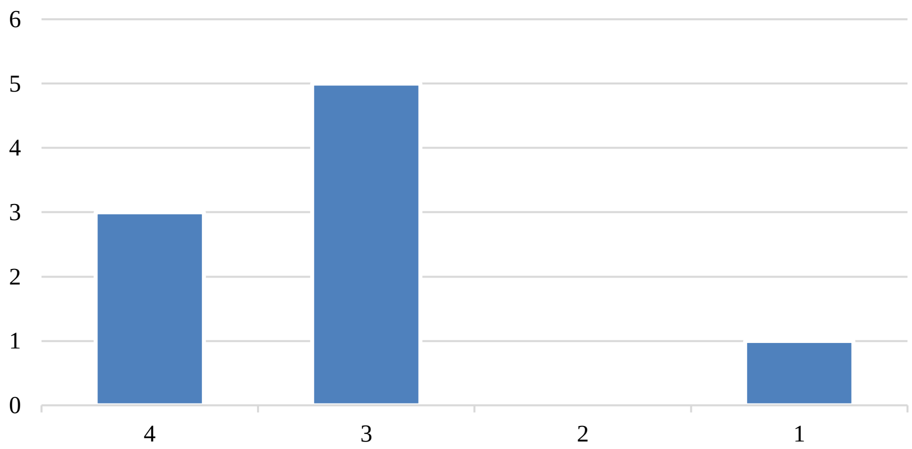


Figure 21. Answers to the question on the clarity of the concept and content of BAT conclusions (4 = clear, 1 = unclear).

According to the results in Figure 21, most of the operators felt that the concept and content of BAT conclusions are clear or relatively clear to them. The second question related to BAT conclusions was: “Do you think it is clear which limit values (BAT or IED) are effective in which operating modes?” The scale was from 4 to 1, in which 4 was clear and 1 unclear. The results are shown in Figure 22.

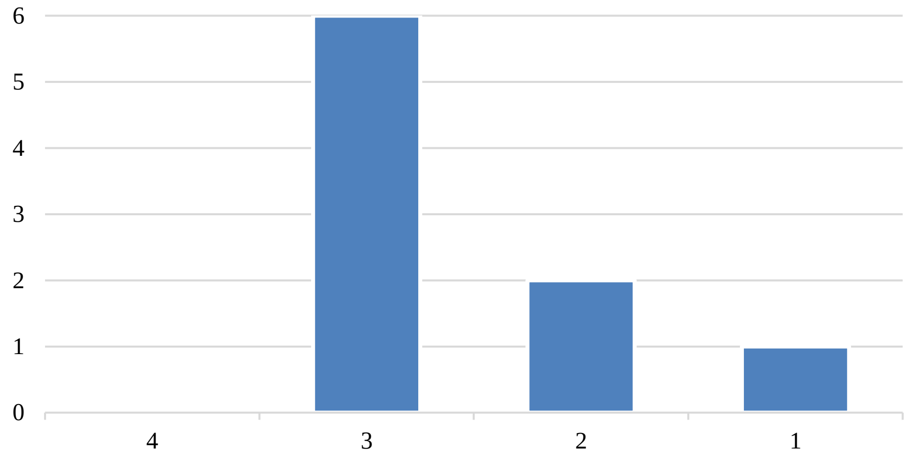


Figure 22. Answers to the question on how clear it is to operators when different emission limit values are effective (4 = clear, 1 = unclear).

According to the results in Figure 22, most of the operators felt that it is relatively clear in which operation modes the emission limit values of the BAT conclusions and the IED are effective. However, three of the respondents thought that it is relatively unclear or unclear.

There was also a question on what kind of OTNOC situations the operators have experienced. The following situations were answered:

- start-up and shutdown
- deviation in fuel content, impurities
- fuel availability problems
- abatement equipment malfunction
- malfunction in handling of condensate in flue gas condenser
- other equipment malfunction
- deviation in combustion conditions
- low steam production
- bypass of steam turbine e.g. in maintenance situations (boiler operates in low power, only district heat produced)
- formation of oxide layer on boiler surfaces after annual maintenance (peat with high sulphur content is used as fuel for 1-2 weeks after the maintenance)
- process malfunction

- special occasions in gas producing units (blast furnace and coke oven)
- solid fuel feeding problems (→ combustion of backup fuel)

Most of the operators consider that determining possible OTNOC situations is relatively straightforward. However, the situations are not fully unambiguous - unexpected situations, that are not in the environmental permit, can occur.

The second part of the survey concerned the standard EN 17255-1. The first question aimed to clarify how aware the operators are of the standard. The question was “Are you aware of the standard and its requirements for the handling and reporting of emissions data?”. Three options were given to the respondents: “yes”, “to some extent” and “not at all”. The results are shown in Figure 23.

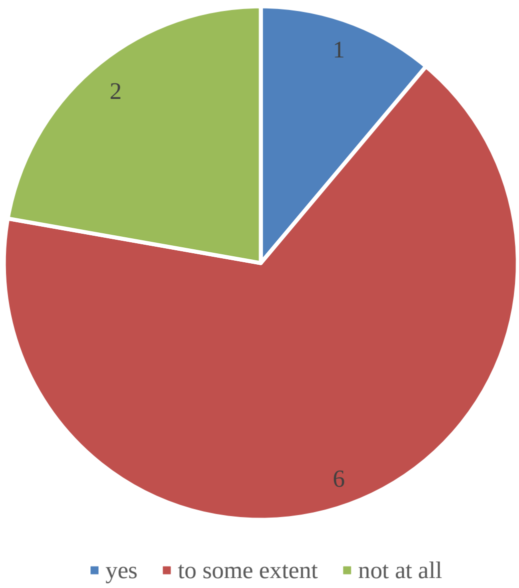


Figure 23. Answers to the question if the operators are aware of the standard and its requirements.

As it can be seen from Figure 23, most of the operators were somewhat aware of the standard. However, full understanding on how it affects handling and reporting of emission data was lacking. The survey also clarified whether the operators feel they need more information about the standard. Six of the respondents (67 %) answered affirmatively.

As mentioned in chapter 5.2, the standard does not advice to calculate mass emissions separately for different operation modes or for different time periods. However, in some cases, it may be necessary to report the mass emissions more precisely. Therefore, the survey aimed to find out whether the operators see more detailed mass emission reporting beneficial. According to the results, seven of the respondents (78 %) see reporting of mass emissions beneficial also in daily and monthly reports. Six of the respondents (67 %) thought that its beneficial to report emissions for multiple operating modes instead of one total value for all reportable modes.

The last question addressed the reporting requirements for QAL2. The standard EN 14181 suggests the plant owner to evaluate the valid calibration range on a weekly basis and to carry out QAL2 if certain conditions occur. The same weekly reporting requirements are in the standard EN 17255-1, but there are also additional requirements for the reporting of QAL2. The aim of the question was to find out how frequently the operators monitor the validity of the calibration function currently. The answers are shown in Figure 24.

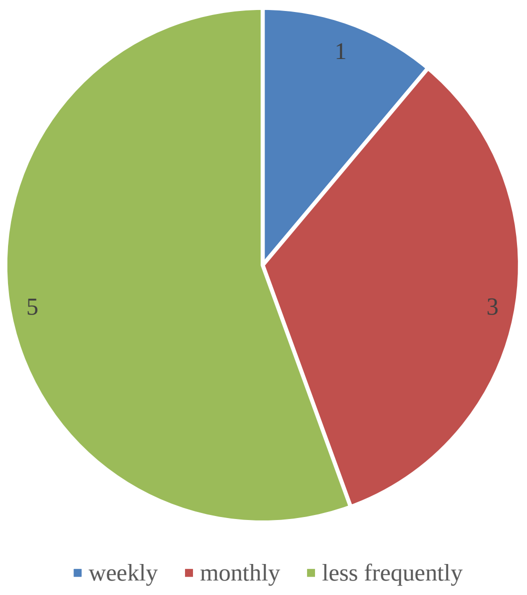


Figure 24. Answers on how often the operators monitor the validity of QAL2 calibration function.

According to the results in Figure 24, most of the operators monitor the validity of the calibration function less frequently than monthly. Therefore, it can be assumed that the new more detailed reporting requirements on QAL2 will not add value to operators.

6 VALMET EMRS COMPLIANCE WITH RECENT REQUIREMENTS

To comply with the latest requirements, updates are required to the Valmet Emission Monitoring and Reporting System. The implementation of the standard EN 17255-1 requires changes in the calculation and validation rules of the solutions. As there have previously been no standards for determining operational requirements for EMRSs, the calculation principles and validation rules of Valmet's monitoring and reporting solutions have been developed in cooperation with Finnish authorities and power plant operators. This study aimed to find out about the impacts of the standard's implementation and therefore an analysis of results according to its calculation principles and validation rules was done. The results were compared against the results from Valmet DNA WI Emission Monitoring application. The analysis is in the chapter 6.1.

As a practical part of this study, the LCP BAT conclusions were implemented to the Valmet EMRS. The implementation included BAT-associated emission limit monitoring and OTNOC reporting. The work was part of a larger development project in which also the EN 17255-1 will later be implemented to the Valmet EMRS. Implementation of the LCP BAT conclusions is described in the chapter 6.2.

6.1 Comparison of Current Valmet DNA WI Emission Monitoring Results Against EN 17255-1 Calculation and Validation Rules

Analysis of the EN 17255-1 calculation results against the results acquired by the Valmet DNA WI Emission Monitoring was performed on Valmet DNA demo environment. The both calculation models were implemented on the environment and the calculations were performed with simulated 1-minute emission data. Comparison of the calculation results was done to validated SO_2 concentrations and mass emissions in half-hourly and daily level.

In both calculations, the standardization of measured concentration values was done similarly as in the Equation 1, except that the conversion to standard temperature and pressure was not required, because the measured values were already in the unit of $mg/m^3(n)$.

Therefore, the conversion to dry conditions and the reference oxygen content (6 %) was performed as follows:

$$c_{\mathrm{SO2\_ref}} = c_{\mathrm{SO2\_moist(NTP)}} \cdot \frac{100}{100-h_{\mathrm{m}}} \cdot \frac{21-6}{21-o_{\mathrm{m}}}, \qquad (3)$$

where

$c_{\mathrm{SO2\_ref}}$ SO_2 content of dry flue gas in reference oxygen content (mg/m^3(n)),

$c_{\mathrm{SO2\_moist(NTP)}}$ SO_2 content of moist flue gas in NTP conditions (mg/m^3(n)),

h_{m} measured water vapour content of flue gas (%),

o_{m} measured oxygen content of dry flue gas (%).

For the conversion to reference oxygen content, the measured oxygen content of moist gas was converted to dry flue gas as follows:

$$o_{\mathrm{m}} = o_{\mathrm{m\_moist}} \cdot \frac{100}{100-x_{\mathrm{H2O}}}, \qquad (4)$$

where

$o_{\mathrm{m\_moist}}$ oxygen content of moist flue gas (%).

The uncertainty reduction was calculated from the measured value. The equation was:

$$c_{\mathrm{SO2}} = c_{\mathrm{SO2\_ref}} - \left(\frac{k_{\mathrm{95\_SO2}}}{100} \cdot c_{\mathrm{SO2\_ref}}\right), \qquad (5)$$

where

c_{SO2} validated SO_2 concentration (mg/m^3(n)),

$k_{\mathrm{95\_SO2}}$ 95 % confidence factor for SO_2 (20 %).

Mass emissions were calculated as follows:

$$X_{\mathrm{SO2}} = c_{\mathrm{SO2\_ref}} \cdot Q_{\mathrm{fg}} \cdot t \cdot 10^{-6}, \qquad (6)$$

where

X_{SO2} total mass emissions of SO_2 (kg),

Q_{fg} volumetric flow of dry flue gas in NTP conditions (m^3(n)/s),

t calculation cycle (s).

Conversion of flue gas flow to dry conditions was done as follows:

$$Q_{\mathrm{fg}} = Q_{\mathrm{fg\_moist(NTP)}} \cdot \frac{100}{100-h_{\mathrm{m}}}, \qquad (7)$$

where

$Q_{fg\_moist(NTP)}$ volumetric flow of moist flue gas in NTP conditions (mg/m^3(n)).

Table 4 shows comparison of the concentration results. The table includes half-hours from 9:00 to 15:30 but results of the entire day can be seen in Appendix I. Results are displayed at the start time of the calculation cycle. The results in the first column are from the calculation with Valmet DNA WI Emission Monitoring application and the results in the second column are from the calculation according to EN 17255-1 calculation and validation rules. The absolute difference between the results is calculated to the rightmost columns in mg/m^3(n) and as a percentage.

Table 4. Comparison of concentration results.

	DNA WI Emission Monitoring	EN 17255-1	Differences between the results	
Time	c_{SO2} mg/m^3(n)	c_{SO2} mg/m^3(n)	Δc_{SO2} mg/m^3(n)	Δc_{SO2} %
00:00 - 9:00	-	-	-	-
9:00	44,04	43,96	0,07	0,17
9:30	47,23	47,20	0,02	0,05
10:00	45,37	45,33	0,05	0,10
10:30	45,79	45,84	0,06	0,13
11:00	47,93	48,42	0,49	1,02
11:30	0,00	0,00	0,00	0,00
12:00	0,00	0,00	0,00	0,00
12:30	0,00	0,00	0,00	0,00
13:00	0,00	0,00	0,00	0,00
13:30	47,59	0,00	47,59	100,00
14:00	45,04	44,98	0,06	0,14
14:30	48,29	48,18	0,10	0,21
15:00	47,00	46,90	0,10	0,22
15:30	46,51	46,46	0,05	0,11
15:30 - 24:00	-	-	-	-
Daily average	46,86	46,75	0,11	0,24

The simulated plant was in reportable mode, i.e. normal operation, other periods than 11:21-13:47. As it can be seen from the Table 4, the difference between the calculation results during normal operation was not remarkable – averagely 0,24 %. The biggest difference in half-hourly concentration averages occurred when the operation mode of the plant changed from non-reportable to reportable mode in 13:30–14:00. During that half an hour, the plant was in reportable mode less than 2/3 of the period meaning that the two-thirds rule of the standard was not fulfilled. The difference between the results was 100 %. At 11:00-11:30, when the operation mode changed from reportable to non-reportable mode, the difference was 1,02 %. The difference was not remarkable as the 2/3 rule of the standard was fulfilled.

Based on the results of the comparison, calculation order does not significantly affect the results. It should be noted though, that temperature and pressure conversion was not included in the calculations. Differences in the validation rules have a more significant impact on the results. In addition to the 2/3 rule, a difference occurs if there is less than 6 h of normal operation during the day. In that case, the calculation according to the standard's validation and calculation rules would set the daily concentration to zero.

Comparison of mass emission results in the selected time period can be seen in Table 5 and comparison of the whole day can be seen in Appendix I.

Table 5. Comparison of mass emission results.

	DNA WI Emission Monitoring	EN 17255-1	Differences between the results	
Time	X_{SO2} kg	X_{SO2} kg	ΔX_{SO2} kg	ΔX_{SO2} %
00:00 - 9:00	-	-	-	-
9:00	10,96	10,96	0,00	0,00
9:30	11,67	11,66	0,01	0,04
10:00	11,06	11,06	0,00	0,02
10:30	11,27	11,27	0,00	0,00
11:00	11,91	11,91	0,00	0,01
11:30	12,33	12,33	0,00	0,02
12:00	12,42	12,42	0,00	0,01
12:30	12,45	12,45	0,00	0,00
13:00	12,20	12,20	0,00	0,00
13:30	12,17	12,17	0,00	0,01
14:00	10,83	10,83	0,00	0,01
14:30	11,51	11,50	0,00	0,02
15:00	11,24	11,24	0,00	0,01
15:30	11,06	11,06	0,00	0,02
15:30 - 24:00	-	-	-	-
Daily average	11,42	11,42	0,00	0,01

As it can be seen from the Table 5, the difference in mass emissions was neglectable. During the day, the average of percentual difference was 0,01 %. Thus, it does not seem to have a remarkable effect on the result whether mass emissions are calculated from minute or half-hourly averages. However, the comparison was done to the total value during all operation modes. According to the standard, only one total value during all operation modes is calculated while the Valmet DNA WI Emission Monitoring solution calculates mass emissions also separately for normal operation, start-up and shutdown and abatement equipment faults.

6.2 Implementation of LCP BAT Conclusions

The practical part of this study was the implementation of the requirements of the LCP BAT conclusions to Valmet's emission monitoring and reporting solutions in cooperation with the application development team in Valmet Automation. The work was done using Valmet DNA Historian calculation environment, Valmet DNA Report tools and the Valmet DNA Report Diary. Developed features complement Valmet's existing emission reporting solutions so that the requirements of the LCP BAT conclusions are met. The solution can be used for BAT compliance monitoring in LCPs or in waste co-incineration plants. The solution consists of a calculation library, emission reports and an OTNOC reporting feature. OTNOC events are reported using the DNA Report Diary, which is an electronic logbook. The events are recorded automatically based on data from automation or manually on an OTNOC entry form. Emissions during OTNOC are excluded from the calculation of concentration averages.

The application performs calculation every half-an-hour (co-incineration plants) or every hour (LCPs). The calculation takes in concentration values and other needed inputs from Valmet DNA LCP or WI Emission Monitoring application. OTNOC information is retrieved from the Valmet DNA Report Diary database. Based on the input data, concentration averages, total emissions and operating times are calculated. Cumulative values of concentration averages can be utilized in online monitoring as they indicate whether the value is going to comply with the emission limit. The calculation also produces a prediction of the daily average. Daily limit exceedances and invalidated days are flagged and recorded to the database. Flow chart of the calculation is shown in Figure 25.

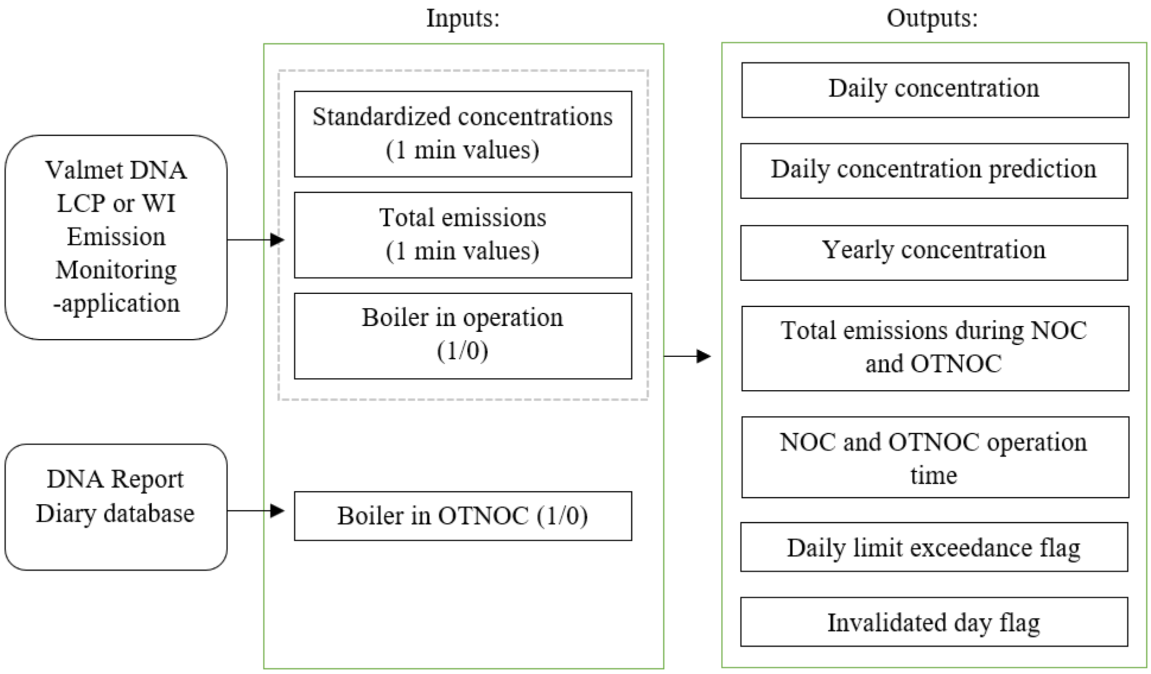


Figure 25. Flow chart of the calculation.

The calculation includes parameters that can be used to configure the calculation to meet the environmental permit of the plant. For example, the uncertainty reduction can be calculated from the emission limit value or from the emission concentration, depending on the local legislation. The outputs of the calculation are stored into the DNA Historian database. The values are displayed on daily, monthly and yearly reports on the DNA Report web-based portal. Figure 26 and Figure 27 show two sheets of the yearly report: NO_x and SO_2 emissions sheet and the process values sheet. The data on the report is simulated.

YEARLY REPORT (BAT) Valmet

2020 Plant Printing Time: 03/03/2021 11:06 AM

	NOx					SO2				
	Daily Limit Value (110%) 231 mg/m³(n)		Yearly Limit Value 180 mg/m³(n)			Daily Limit Value (110%) 192.5 mg/m³(n)		Yearly Limit Value 70 mg/m³(n)		
Month	Monthly Average mg/m³(n)	Daily Exceedings -	NOC t	OTNOC t	Total t	Monthly Average mg/m³(n)	Daily Exceedings -	NOC t	OTNOC t	Total t
January	0.0	0	0.00	0.00	0.00	0.0	0	0.00	0.00	0.00
February	0.0	0	0.00	0.00	0.00	0.0	0	0.00	0.00	0.00
March	81.5	0	35.43	0.00	35.43	71.8	0	30.46	0.00	30.46
April	81.6	0	34.26	0.00	34.26	71.8	0	29.47	0.00	29.47
May	77.5	0	34.29	0.00	34.29	67.4	0	29.25	0.00	29.25
June	71.2	0	31.42	0.00	31.42	63.9	0	27.31	0.00	27.31
July	79.3	0	34.84	0.00	34.84	69.9	0	29.96	0.00	29.96
August	81.5	0	35.46	0.00	35.46	71.8	0	30.51	0.00	30.51
September	81.5	0	34.32	0.00	34.32	71.8	0	29.52	0.00	29.52
October	81.6	0	35.54	0.00	35.54	71.8	0	30.55	0.00	30.55
November	81.5	0	34.33	0.00	34.33	71.8	0	29.52	0.00	29.52
December	85.2	0	36.47	0.00	36.47	71.8	0	30.46	0.00	30.46
Average	80.1					70.6 !				
Sum		0	346.37	0.00	346.37		0	297.01	0.00	297.01
Minimum	0.0	0	0.00	0.00	0.00	0.0	0	0.00	0.00	0.00
Maximum	85.2	0	36.47	0.00	36.47	71.8	0	30.55	0.00	30.55

0,0'	Uncertainty substraction sets concentration value to zero
red!	At least one daily mean value exceeds 110% of the daily limit or the yearly mean value exceeds the yearly limit
INVALID	Not enough valid data for calculating concentration mean value
NOC	Normal Operating Conditions
OTNOC	Other Than Normal Operating Conditions

Figure 26. NO_x and SO_2 emissions sheet.

YEARLY REPORT (BAT)

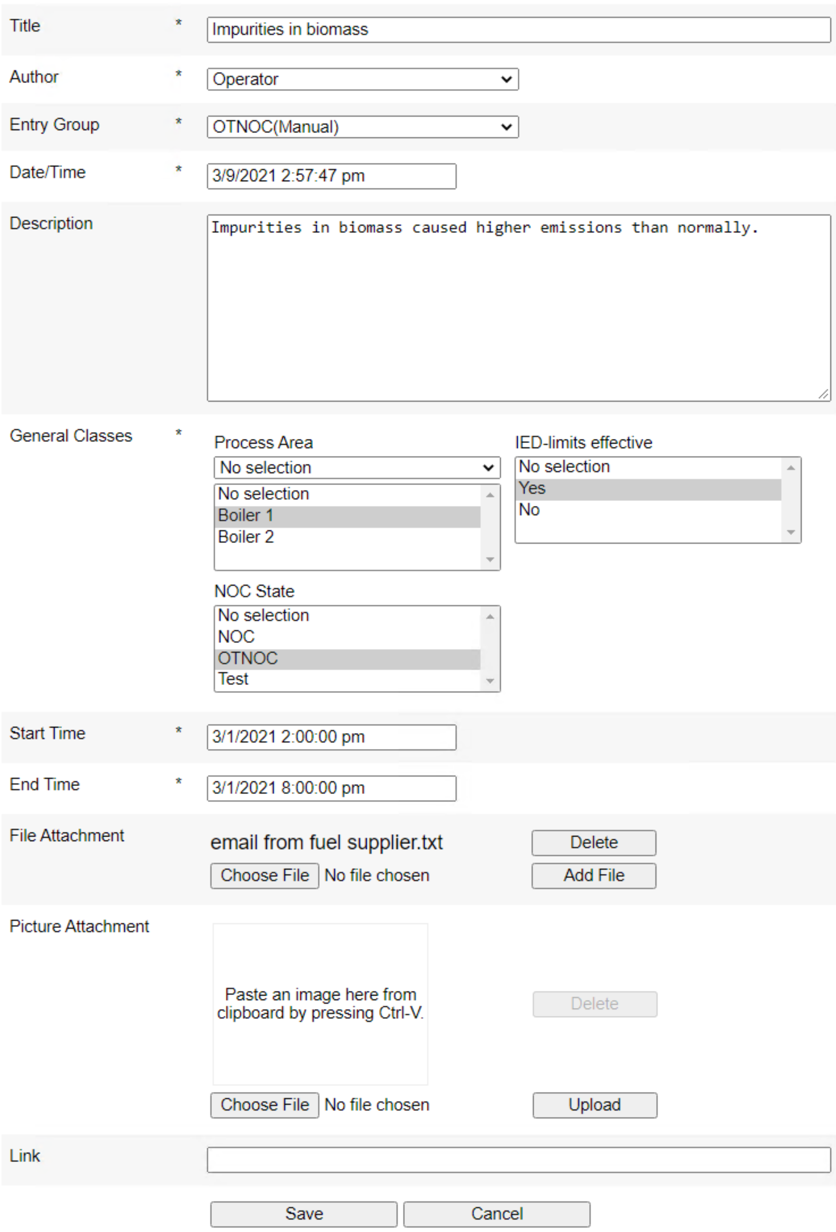
2020 Plant Printing Time: 03/03/2021 11:06 AM

	Operating Times			Disturbance Times		Rejected Days	
Month	Boiler in Operation days	NOC Operation days	OTNOC Operation days	FTIR h	Dust h	FTIR days	Dust days
January	0.0	0.0	0.0	0.0	0.0	0	0
February	0.0	0.0	0.0	0.0	0.0	0	0
March	30.7	30.9	0.0	0.0	0.0	0	0
April	29.6	29.9	0.1	17.0	0.0	4	0
May	28.0	31.0	0.0	0.0	0.0	0	0
June	24.0	30.0	0.0	0.0	0.0	0	0
July	30.4	31.0	0.0	0.0	0.0	0	0
August	29.2	31.0	0.0	0.0	0.0	0	0
September	29.9	30.0	0.0	0.0	0.0	0	0
October	31.0	31.0	0.0	0.0	0.0	0	0
November	29.9	30.0	0.0	0.0	0.0	0	0
December	31.0	30.9	0.1	0.0	0.0	0	0
Sum	353.8	305.8	0.1	17.0	0.0	4	0
Minimum	24.0	0.0	0.0	0.0	0.0	0	0
Maximum	31.0	31.0	0.1	17.0	0.0	4	0

red*	Number of rejected days exceeds 10
NOC	Normal Operating Conditions
OTNOC	Other Than Normal Operating Conditions

Figure 27. Process values sheet.

Information of OTNOC events is automatically recorded to the DNA Report Diary. The automatic recording feature utilizes the DNA Eco Diary, which has previously been used to record emission limit exceedances and other environmental events. Now the Eco Diary was further developed to automatically record predefined OTNOC events. Such events can be for example start-ups, shutdowns and cleaning equipment malfunctions. If other OTNOC happen, an OTNOC entry form can be used to manually record the event. The form can be configured to meet the plant's needs. An example configuration of the OTNOC entry form is in Figure 28.



Title * Impurities in biomass
Author * Operator
Entry Group * OTNOC(Manual)
Date/Time * 3/9/2021 2:57:47 pm
Description: Impurities in biomass caused higher emissions than normally.
General Classes *
Process Area: No selection / No selection, Boiler 1, Boiler 2
IED-limits effective: No selection, Yes, No
NOC State: No selection, NOC, OTNOC, Test
Start Time * 3/1/2021 2:00:00 pm
End Time * 3/1/2021 8:00:00 pm
File Attachment: email from fuel supplier.txt — Delete — Choose File No file chosen — Add File
Picture Attachment: Paste an image here from clipboard by pressing Ctrl-V. — Delete — Choose File No file chosen — Upload
Link
Save Cancel

Figure 28. An example configuration of the OTNOC entry form.

The entry form contains basic information of the event and classes, that are used to define in which area of the plant the event occurred and whether the event was included in monitoring under the IED. Classes can be used later to filter the events on a summary report. If a faulty OTNOC entry is done, the NOC state can be changed from OTNOC to NOC, so the entry does not affect the concentration calculations.

All the manually and automatically entered OTNOC events can be viewed on an OTNOC summary report. A detailed view of the event displays all the recorded information of it. Example of a summary report and a detailed view is shown in Figure 29.

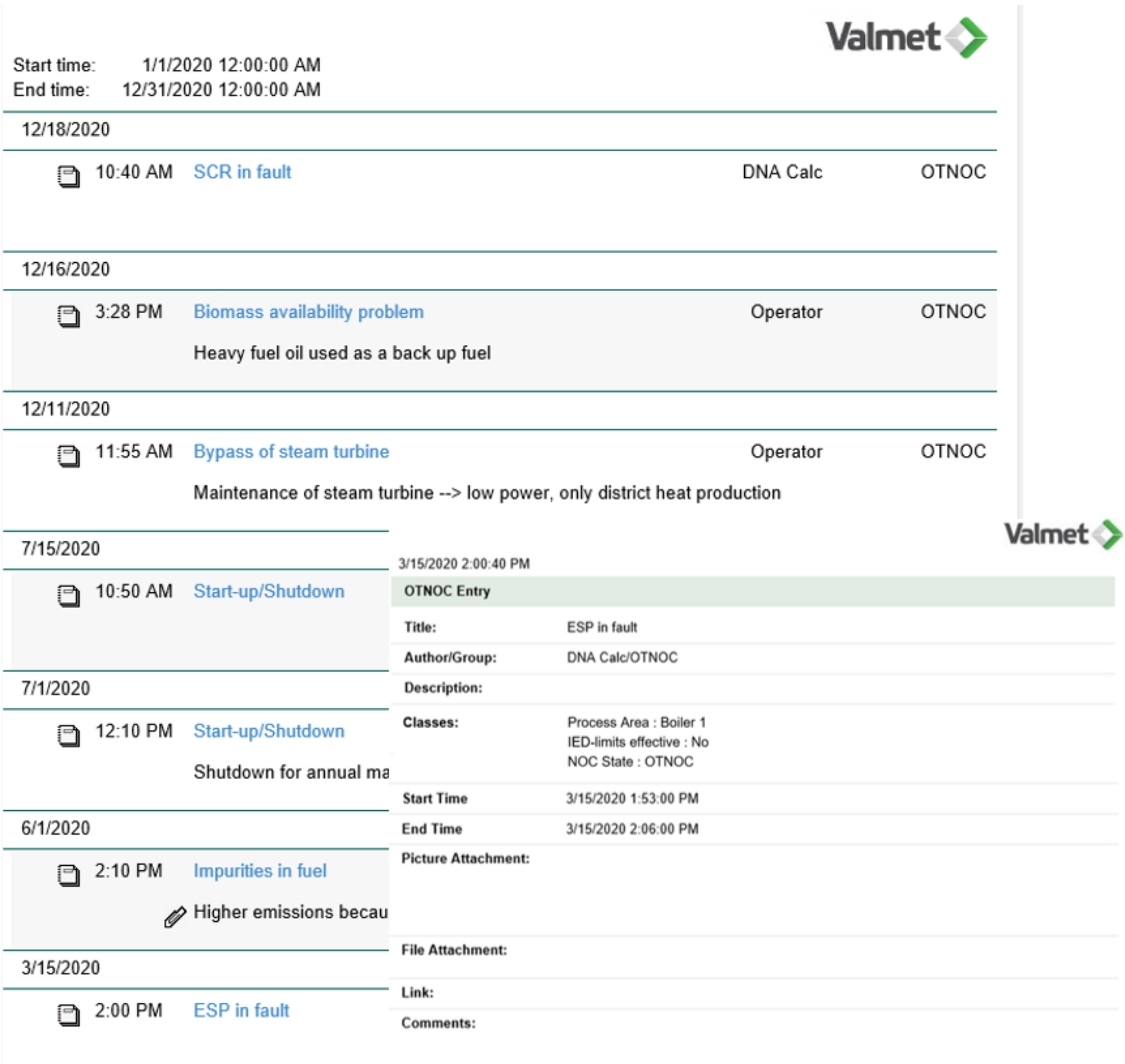


Figure 29. OTNOC summary report and a detailed view.

7 CONCLUSIONS

The purpose of this study was to clarify the current requirements for air emission monitoring and reporting in energy production in the EU. The focus was on recently published requirements which in this study referred to the updated BAT Reference Documents for LCPs and WI plants, as well as the new EN standard 17255-1, which regulates emission monitoring and reporting systems. The final objective of this study was to ensure that the Valmet EMRS complies with the latest requirements.

As a part of the study, the new requirements were discussed with Finnish authorities and an operator survey was conducted. Outcomes of the discussions and the survey were utilized in the implementation of the requirements. The discussions with the authorities clarified that the standard EN 17255-1 is not yet included in legislative requirements in Finland. The study stated that the standard’s requirements are not entirely unambiguous and detailed interpretations are still needed. Also, answers to the operator survey showed that more information about the standard would be necessary. Nevertheless, as the first standard determining requirements for EMRSs, its implementation is important for the harmonization of emission monitoring and reporting in the EU. It is likely that different interpretations of the standard will be done across the EU and thus its implementation is only the first step towards consistent reporting. The study compared results according to the standard’s calculation procedures and validation rules to results acquired by the Valmet DNA WI Emission Monitoring application. The biggest differences appeared when the operation mode of the plant changed, since validation rules of the calculations differ. Results in normal operation did not differ remarkably.

Requirements of the BAT reference document for LCPs were implemented to the Valmet EMRS in cooperation with the application development team in Valmet Automation. The implementation includes monitoring of compliance with the BAT ELVs and OTNOC reporting. According to the discussions with the authorities, ELVs defined in the IED must always be monitored simultaneously with the BAT ELVs. Thus, the solution was developed to work with Valmet’s existing emission monitoring and reporting solutions that are based on the requirements of the IED. The solution calculates necessary concentration averages, mass emissions and operation times and displays them on daily, monthly and yearly reports.

Emissions during OTNOC situations are excluded from the concentration calculations. The situations are entered to the database automatically based on the data from automation or manually in Valmet DNA Report Diary. All the OTNOC events entered into the database can be viewed on a summary report.

The study took also a brief look into the future and upcoming changes in the requirements for emission monitoring. The EU has made an evaluation of the IED and identified problems to be addressed in an impact assessment. These problems are, for instance, varying interpretations of compliance monitoring rules and conflicting regimes of the IED and the BAT conclusions. The problems include simultaneous monitoring of emission limit values defined in the BAT conclusions and the IED, which was also discussed in this study. The assessment also considers options to integrate real-time emission reporting to Member States' databases as it would improve transparency of the reporting. Based on the impact assessment, the EU will make a legislative proposal for the revision of the IED at the end of 2021. In addition, guidance for the implementation of the standard series EN 17255 in Finland is expected. Thus, development of the Valmet EMRS in accordance with the latest regulations and technologies will continue also in the future.

REFERENCES

Becker, Christoph. EN 17255 - The world's first international Data Acquisition and Handling System standard. CEM 2021 – Presentation abstract. [Online]. [Accessed 14.1.2021]. Available at https://www.ilmexhibitions.com/cem/abstract/EN+17255+-+The+world%E2%80%99s+first+international+Data+Acquisition+and+Handling+System+standard/1128/

CEN (European Committee for Standardization). 2014. EN 14181: Stationary source emissions. Quality assurance of automated measuring systems. Brussels. 59 p.

CEN (European Committee for Standardization). 2019. Stationary source emissions - Data acquisition and handling systems - Part 1: Specification of requirements for the handling and reporting of data. Brussels. 37 p.

CEN (European Committee for Standardization). 2020a. Stationary source emissions - Data acquisition and handling systems - Part 2:
Specification of requirements on data acquisition and handling systems. Brussels. 18 p.

CEN (European Committee for Standardization). 2020b. Stationary source emissions - Data acquisition and handling systems - Part 3: Specification of requirements for the performance test of data acquisition and handling systems (draft). Brussels. 16 p.

CMS. 2021. BAT conclusions for large combustion plants annulled – What next? [Online]. [Accessed 14.1.2021]. Available at https://www.cms-lawnow.com/ealerts/2021/02/bat-conclusions-for-large-combustion-plants-annulled-what-next?cc_lang=en

Decree 936/2014 on Limiting Emissions from Large Combustion Plants. Ministry of the Environment. Helsinki. 13.11.2014.

Decree 151/2013 on Waste Incineration. Ministry of the Environment. Helsinki. 14.2.2013.

Department of Environment Malaysia. 2019. Guidelines for the installation & maintenance of continuous emission monitoring systems (CEMS) for industrial premises/facilities. [Online]. [Accessed 14.1.2021]. Available at https://www.doe.gov.my/portalv1/wp-content/uploads/2013/01/GUIDELINE-FOR-THE-INSTALLATION-MAINTENANCE-OF-CEMS-FOR-INDUSTRIAL-PREMISES-OR-FACILITIES-VERSION-7.0-JUNE-2019.pdf

Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control). Official Journal of the European Union. 17.12.2010. L334, p. 17-119.

Directive 2016/2284/EU of the European Parliament and of the Council of 14 December 2016 on the reduction of national emissions of certain atmospheric pollutants, amending Directive 2003/35/EC and repealing Directive 2001/81/EC. Official Journal of the European Union. L344, 17.12.2016, p. 1–31.

EEA (European Environment Agency). 2010. Non-methane volatile organic compounds (NMVOC) emissions. [Online]. [Accessed 14.1.2021]. Available at https://www.eea.europa.eu/data-and-maps/indicators/eea-32-non-methane-volatile-1

EEA (European Environment Agency). 2019. EMEP/EEA air pollutant emission inventory guidebook 2019: 1.A.1 Energy industries. Luxembourg: Publications Office of the European Union ISBN 978-92-9480-098-5. 116 p.

EEA (European Environment Agency). 2020a. Air quality in Europe - 2020 report. Luxembourg: Publications Office of the European Union. ISBN 978-92-9480-292-7. 160 p.

EEA (European Environment Agency). 2020b. Renewable energy in Europe: key for climate objectives, but air pollution needs attention. [Online]. [Accessed 20.3.2021]. Available at https://www.eea.europa.eu/themes/energy/renewable-energy/renewable-energy-in-europe-key

EEA (European Environment Agency). 2020c. EEA Signals 2020 – Towards zero pollution in Europe. Luxembourg: Publications Office of the European Union. ISBN: 978-92-9480-267-5. 67 p.

EEB (European Environmental Bureau). Industrial Plant Data Viewer. [Online]. [Accessed 14.1.2021]. Available at http://eipie.eu/projects/ipdv
European Commission. Module 2: IED Principles - BAT reference documents and exchange of information 1/2. [Online]. [Accessed 4.1.2021]. Available at https://ec.europa.eu/environment/legal/law/1/module_2_18.htm

European Commission. 2015. EU ETS Handbook. [Online]. [Accessed 14.1.2021]. Available at
https://ec.europa.eu/clima/sites/clima/files/docs/ets_handbook_en.pdf

European Commission. 2017. Best Available Techniques (BAT) Reference Document for Large Combustion Plants. Luxembourg: Publications Office of the European Union. ISBN 978-92-79-74303-0. 940 p.

European Commission. 2018. JRC Reference Report on Monitoring of Emissions to Air and Water from IED Installations - Industrial Emissions Directive 2010/75/EU (Integrated Pollution Prevention and Control). Luxembourg: Publications Office of the European Union. ISBN: 978-92-79-86853-5. 178 p.

European Commission. 2019a. Best Available Techniques (BAT) Reference Document for Waste Incineration. Luxembourg: Publications Office of the European Union. ISBN 978-92-76-12993-6. 728 p.

European Commission. 2019b. The new Industrial Emissions Directive. [Online]. [Accessed 14.1.2021]. Available at https://ec.europa.eu/environment/legal/law/1/module_2_25.htm

European Commission. 2019c. New EU environmental standards for waste incineration. [Online]. [Accessed 14.1.2021]. Available at https://ec.europa.eu/jrc/en/news/new-eu-environmental-standards-waste-incineration

European Commission. 2020a. Industrial Emissions Directive. [Online]. [Accessed 14.1.2021]. Available at https://ec.europa.eu/environment/industry/stationary/ied/legislation.htm

European Commission 2020b. Evaluation of the Industrial Emissions Directive (IED). [Online]. [Accessed 14.1.2021]. Available at https://data.consilium.europa.eu/doc/document/ST-11095-2020-INIT/en/pdf

European Commission. 2020c. Large combustion plants. [Online]. [Accessed 19.11.2020]. Available at https://ec.europa.eu/environment/industry/stationary/lcp/chapter3.htm

European Commission. 2020d. The Medium Combustion Plant Directive. [Online]. [Accessed 30.12.2020]. Available at https://ec.europa.eu/environment/industry/stationary/mcp.htm

European Commission. 2021. Judgment of the General Court (Third Chamber, Extended Composition) of 27 January 2021. Republic of Poland v European Commission. Available at https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A62017TJ0699

European Commission & Ricardo. 2020. Revision of the Industrial Emissions Directive (IED). First stakeholder workshop 15 December 2020. [Online]. [Accessed 12.1.2021]. Available at https://d1v9sz08rbysvx.cloudfront.net/ee/media/assets/ied-ia-s_h-workshop-15dec20-slides-final.pdf

Eurostat. 2020a. Electricity and heat statistics. [Online]. [Accessed 29.12.2020]. Available at https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_and_heat_statistics

Eurostat. 2020b. Electricity generation statistics - first results. [Online]. [Accessed 14.1.2021]. Available at https://ec.europa.eu/eurostat/statistics-explained/pdfscache/9990.pdf

Eurostat. 2020c. How are emissions of greenhouse gases by the EU evolving? [Online]. [Accessed 27.11.2020]. Available at https://ec.europa.eu/eurostat/cache/infographs/energy/bloc-4a.html

Feeley, Thomas J & Brickett, Lynn A. & Murphy, James T. 2003. Evaluation of the Effect of SCR NOx Control Technology on Mercury Speciation. U.S. Department of Energy. [Online]. [Accessed 14.1.2021]. Available at http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.151.6335&rep=rep1&type=pdf

Gillenwater, Michael. 2005. Calculation tool for direct emissions from stationary combustion. Environmental Resources Trust. [Online]. [Accessed 14.1.2021]. Available at https://www.ghgprotocol.org/sites/default/files/ghgp/Stationary_Combustion_Guidance_final_1.pdf

Hiltunen, Erkki et al. 2011. Laadukkaan mittaamisen perusteet. Espoo, Finland: Metrologian neuvottelukunta ja Mittatekniikan keskus (MIKES). ISBN 978-952-5610-75-8. 134 p.

IEA (International Energy Agency). 2020. World Energy Balances: Overview. [Online]. [Accessed 14.1.2021]. Available at https://www.iea.org/reports/world-energy-balances-overview#world

Jahnke, James A. 2000. Continuous Emission Monitoring. USA: John Wiley & Sons. ISBN: 978-0-471-29227-2. 416 p.

Karjalainen, Anneli. 2016. Suurten polttolaitosten päästöjen rajoittaminen ja joustojen käyttö. [PowerPoint Presentation] Polttolaitokset ja päästösääntely. Scandic Park, Helsinki. 7.4.2016.

Ministry of the Environment. 2017. Ohje suurten polttolaitosten (LCP) parhaita käyttökelpoisia tekniikoita (BAT) koskevien päätelmien soveltamisesta. [Online]. [Accessed 14.10.2021]. Available at https://ym.fi/documents/1410903/38678498/Ohje+suurten+polttolaitosten+BAT-p%C3%A4%C3%A4telmien+soveltamisesta.pdf/1327657c-c284-8f16-91b6-e5c080ae6e44/Ohje+suurten+polttolaitosten+BATp%C3%A4%C3%A4telmien+soveltamisesta.pdf?t=1605688739054

Ministry of the Environment. 2019. Ohje jätteenpolton (WI) parhaita käyttökelpoisia tekniikoita (BAT) koskevien päätelmien soveltamisesta. [Online]. [Accessed 14.10.2021]. Available at https://ym.fi/documents/1410903/38678498/Ohje+j%C3%A4tteenpolton+BAT-p%C3%A4%C3%A4telmien+soveltamisesta.pdf/8af76314-670d-f646-dda6-709487e66f08/Ohje+j%C3%A4tteenpolton+BAT-p%C3%A4%C3%A4telmien+soveltamisesta.pdf?t=1605688192099

National Research Council. 2002. The Ongoing Challenge of Managing Carbon Monoxide Pollution in Fairbanks, Alaska: Interim Report. Washington, DC: The National Academies Press. ISBN 978-0-309-18275-1.

Novox Oy. 2018. Suurten polttolaitosten BAT 2017 - Päätelmien soveltaminen - Tekninen ohjeistus. [Online]. [Accessed 3.11.2020]. Available at https://ym.fi/documents/1410903/38678498/Suurten+polttolaitosten+BAT-p%C3%A4%C3%A4telmien+soveltamisen+tekninen+ohjeistus.pdf/2b47b52d-618d-6593-7766-5925e5769034/Suurten+polttolaitosten+BAT-p%C3%A4%C3%A4telmien+soveltamisen+tekninen+ohjeistus.pdf?t=1605688795650

Pandey, Sudhir Kumar & Kim, Ki-Hyun & Brown, Richard J.C. 2011. Measurement techniques for mercury species in ambient air. TrAC Trends in Analytical Chemistry. Volume 30, Issue 6, June 2011. ISSN 0165-9936. p. 899-917.

Pellikka, Tuula. 2019. Päästömittausten haasteet alhaisilla pitoisuustasoilla. [Online]. [Accessed 3.11.2020]. Available at https://isy.fi/wp-content/uploads/2019/08/2108_4B_T_Pellikka_P%C3%A4%C3%A4st%C3%B6mittausten-haasteet.pdf

Ricardo. 2021. Supporting study for an assessment of options for the revision of the Industrial Emissions Directive – Targeted Stakeholder Survey Questionnaire. [PDF] Available on request.

Russell, Armistead (Ted). 2013. Chapter 4. Combustion Emissions. IARC Scientific Publication No. 161. Lyon, France: WHO Press. ISBN 978-92-832-2166-1. p. 37-47.

SYKE (Finnish Environment Institute). 2016, updated 2020. Paras käyttökelpoinen tekniikka BAT. [Online]. [Accessed 15.10.2020]. Available at https://www.ymparisto.fi/bat

Szentennai, Pal & Lackner, Maximilian. 2014. Advanced control methods for combustion. [Online]. [Accessed 25.3.2021]. Available at https://www.chemengonline.com/advanced-control-methods-for-combustion/?printmode=1

TEM (Työ- ja elinkeinoministeriö) a. Emissions Trading Directive. [Online]. [Accessed 17.12.2020]. Available at https://tem.fi/en/emissions-trading-directive

TEM (Työ- ja elinkeinoministeriö) b. Päästökauppa. [Online]. [Accessed 17.12.2020]. Available at https://tem.fi/paastokauppa

Toikka, Mika. 2020. Lupasuureiden valvonta ja viranomaisvelvoitteet. Lecture material: Ympäristöluvat ja -mittaukset. LUT University. Available for course participants.

Valmet a. Emission monitoring and reporting solutions. [Online]. [Accessed 29.12.2020] Available at https://www.valmet.com/automation/applications/energy/emission-monitoring-reporting/

Valmet b. Valmet DNA Information Management. [Online]. [Accessed 29.12.2020]. Available at https://www.valmet.com/automation/distributed-control-system/information-management/

Valmet. 2017. Valmet DNA FBB Combustion Manager – Sales Material. Unpublished material.

Valmet. 2019. Valmet DNA Emission Monitoring and Reporting System – Customer Training. Unpublished material.

VTT. 2004. Päästömittausten käsikirja – Osa 3: Laitevalmistajien näkemykset päästömittausjärjestelmistä ja käytännön laadunvarmistuksesta. [Online]. [Accessed 29.10.2020]. Available at https://ilmansuojeluyhdistys.files.wordpress.com/2015/05/osa3.pdf

VTT. 2007. Päästömittausten käsikirja – Osa 1: Päästömittaustekniikan perusteet. [Online]. [Accessed 29.10.2020]. Available at https://ilmansuojeluyhdistys.files.wordpress.com/2015/05/osa1.pdf

VTT. 2016. Suomessa käytettävien polttoaineiden ominaisuuksia. Espoo, Finland: Teknologian tutkimuskeskus VTT Oy. ISBN 978-951-38-8418-5. 229 p.

WECOOP (EU – Central Asia Cooperation on Water – Environment – Climate Change). EU Environmental Policy Overview. [Online]. [Accessed 4.1.2021]. Available at https://wecoop.eu/regional-knowledge-centre/eu-policies-regulation

APPENDIX I: Comparison of results from Valmet DNA WI Emission Monitoring application and the calculation according to calculation principles and validation rules of the standard EN 17255-1.

Table 1. Comparison of concentration results.

	DNA WI Emission Monitoring	EN 17255-1	Differences between the results	
Time	c_{SO2} mg/m³(n)	c_{SO2} mg/m³(n)	Δc_{SO2} mg/m³(n)	Δc_{SO2} %
0:00	45,49	45,38	0,11	0,25
0:30	47,08	46,89	0,19	0,41
1:00	46,33	46,25	0,08	0,17
1:30	46,28	46,12	0,16	0,35
2:00	48,38	48,24	0,14	0,29
2:30	45,38	45,28	0,10	0,21
3:00	48,41	48,22	0,19	0,39
3:30	48,12	47,98	0,14	0,29
4:00	45,94	45,83	0,11	0,23
4:30	49,25	49,17	0,08	0,16
5:00	47,56	47,42	0,14	0,28
5:30	47,77	47,65	0,12	0,26
6:00	47,79	47,73	0,07	0,14
6:30	46,92	46,81	0,11	0,24
7:00	47,23	47,10	0,13	0,28
7:30	46,26	46,14	0,12	0,25
8:00	46,29	46,23	0,06	0,14
8:30	47,24	47,18	0,06	0,12
9:00	44,04	43,96	0,07	0,17
9:30	47,23	47,20	0,02	0,05
10:00	45,37	45,33	0,05	0,10
10:30	45,79	45,84	0,06	0,13
11:00	47,93	48,42	0,49	1,02
11:30	0,00	0,00	0,00	0,00
12:00	0,00	0,00	0,00	0,00
12:30	0,00	0,00	0,00	0,00
13:00	0,00	0,00	0,00	0,00
13:30	47,59	0,00	47,59	100,00
14:00	45,04	44,98	0,06	0,14
14:30	48,29	48,18	0,10	0,21
15:00	47,00	46,90	0,10	0,22
15:30	46,51	46,46	0,05	0,11
16:00	49,69	49,63	0,06	0,11

16:30	46,99	46,89	0,10	0,21
17:00	47,01	46,88	0,12	0,26
17:30	47,31	47,28	0,03	0,06
18:00	45,71	45,47	0,24	0,52
18:30	48,08	47,91	0,17	0,36
19:00	46,02	45,91	0,11	0,23
19:30	45,77	45,69	0,08	0,17
20:00	46,82	46,69	0,13	0,27
20:30	44,58	44,41	0,18	0,40
21:00	47,83	47,72	0,11	0,22
21:30	46,32	46,17	0,15	0,33
22:00	45,82	45,70	0,11	0,25
22:30	47,58	47,44	0,14	0,29
23:00	46,19	46,02	0,16	0,35
23:30	47,58	47,39	0,20	0,41
Daily average	46,86	46,75	0,11	0,24
Minimum	0,00	0,00	0,00	0,00
Maximum	49,69	49,63	47,59	100,00

Table 2. Comparison of mass emission results.

	DNA WI Emission Monitoring	EN 17255-1	Differences between the results	
Time	X_{SO2} kg	X_{SO2} kg	ΔX_{SO2} kg	ΔX_{SO2} %
0:00	11,02	11,03	0,00	0,03
0:30	11,40	11,40	0,00	0,02
1:00	11,31	11,31	0,00	0,00
1:30	11,16	11,16	0,00	0,02
2:00	11,60	11,59	0,00	0,02
2:30	10,93	10,93	0,00	0,01
3:00	11,61	11,61	0,00	0,00
3:30	11,34	11,34	0,00	0,01
4:00	10,99	10,99	0,00	0,02
4:30	11,71	11,71	0,00	0,03
5:00	11,13	11,14	0,00	0,03
5:30	11,34	11,34	0,00	0,01
6:00	11,43	11,43	0,00	0,02
6:30	11,08	11,08	0,00	0,00
7:00	11,44	11,44	0,00	0,00
7:30	11,26	11,26	0,00	0,00
8:00	11,30	11,30	0,00	0,02
8:30	11,54	11,55	0,00	0,03

9:00	10,96	10,96	0,00	0,00
9:30	11,67	11,66	0,01	0,04
10:00	11,06	11,06	0,00	0,02
10:30	11,27	11,27	0,00	0,00
11:00	11,91	11,91	0,00	0,01
11:30	12,33	12,33	0,00	0,02
12:00	12,42	12,42	0,00	0,01
12:30	12,45	12,45	0,00	0,00
13:00	12,20	12,20	0,00	0,00
13:30	12,17	12,17	0,00	0,01
14:00	10,83	10,83	0,00	0,01
14:30	11,51	11,50	0,00	0,02
15:00	11,24	11,24	0,00	0,01
15:30	11,06	11,06	0,00	0,02
16:00	11,72	11,72	0,00	0,01
16:30	11,15	11,15	0,00	0,01
17:00	11,35	11,35	0,00	0,00
17:30	11,30	11,30	0,00	0,02
18:00	11,08	11,08	0,00	0,01
18:30	11,71	11,71	0,00	0,01
19:00	11,29	11,29	0,00	0,01
19:30	11,20	11,20	0,00	0,01
20:00	11,57	11,56	0,00	0,02
20:30	10,90	10,90	0,00	0,04
21:00	11,66	11,66	0,00	0,03
21:30	11,32	11,32	0,00	0,00
22:00	11,26	11,26	0,00	0,02
22:30	11,47	11,47	0,00	0,01
23:00	11,11	11,11	0,00	0,02
23:30	11,57	11,57	0,00	0,03
Average	11,42	11,42	0,00	0,01
Minimum	10,83	10,83	0,00	0,00
Maximum	12,45	12,45	0,01	0,04